Open Research Online

The Open University's repository of research publications
and other research outputs

The influence of stimulus control on the effects of transcutaneous electrical nerve stimulation (TENS) on experimental ischaemic pain

Thesis

How to cite:

Kirk, Kerry Alicia (1998). The influence of stimulus control on the effects of transcutaneous electrical nerve stimulation (TENS) on experimental ischaemic pain. PhD thesis The Open University.

For guidance on citations see FAQs.

© 1997 The Author

https://creativecommons.org/licenses/by-nc-nd/4.0/

Version: Version of Record

Link(s) to article on publisher's website:
http://dx.doi.org/doi:10.21954/ou.ro.0000e163

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data policy on reuse of materials please consult the policies page.

oro.open.ac.uk

UNRESTRICTED

The influence of stimulus control on the effects of transcutaneous electrical nerve stimulation (TENS) on experimental ischaemic pain.

Kerry Alicia Kirk B.Sc. (Hons)

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the discipline of Physiotherapy

AWARDING BODY:
THE OPEN UNIVERSITY

Author no. P927780X
Date of award: 26th January 1998

Queen Margaret College, Edinburgh

September 1997

Acknowledgements

I would like to thank Dr. Denis Martin, Dr. Wilma Steedman and Dr. John Ravey for their advice and encouragement throughout the planning and writing of this thesis. I would also like to thank my partner, Paul, for his assistance with typing and proof-reading and, more importantly, for putting up with me during stressful times!

Finally, I would like to dedicate this thesis to my parents. To my mum, who has always been close at hand to offer unlimited understanding and support and to my dad, who although unable to see the final document, has always been my inspiration.

~ pm

KIRK, I

The Open University

Library authorisation form

Form SE12 (1996)

Please return this form to the Research Degrees Office, Open University Validation Services, 344-354 Gray's Inn Road, London WC1X 8BP. All students should complete Part 1. Part 2 applies only to PhD students.

Student: KERRY ALICIA KIRK PI: P927780X

Sponsoring Establishment: QUEEN MARGARET COLLEGE, EDINBURGH

Degree for which the thesis is submitted: PhD

Thesis title: THE INFLUENCE OF STIMULUS CONTROL ON THE EFFECTS OF TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION (TENS) ON EXPERIMENTAL ISCHAEMIC PAIN.

Part 1 Open University Library Authorisation (to be completed by all students)

I confirm that I am willing for my thesis to be made available to readers by the Open University Library and for it to be photocopied, subject to the discretion of the Librarian.

Signed: Kerry Kirk Date: 20-3-98

Part 2 British Library Authorisation (to be completed by PhD students only)

If you want a copy of your thesis to be available on loan to the British Library Thesis Service as and when it is requested, you must sign a British Library Doctoral Thesis Agreement Form and return it to the Research Degrees Office of the University together with this form. The British Library will publicize the details of your thesis and may request a copy on loan from the University Library. Information on the presentation of the thesis is given in the Agreement form.

The University has decided that your participation in the British Library Thesis Service should be voluntary. Please tick one of the boxes below to indicate your intentions.

☑ I am willing for the Open University to loan the British Library a copy of my thesis; a signed British Library Doctoral Thesis Agreement Form is attached.

or

☐ I do not wish the Open University to loan a copy of my thesis to the British Library.

Signed: Kerry Kirk Date: 20-3-98

Abstract

A review of the relevant literature suggested a number of unresolved issues in the most efficacious use of TENS for pain-relief including the degree of control and the frequency of TENS. The study investigated the influence of giving subjects control of the TENS stimulus on reported pain intensity and unpleasantness during experimental ischaemic pain induction of the arm. The pain induction and assessment procedures were established during an initial series of three experiments. Subjects in these and the subsequent experiments were healthy female student volunteers from Queen Margaret College. A further series of experiments investigated the influence of control of the TENS intensity on VAS scores of pain intensity and unpleasantness. When used, TENS (symmetrical biphasic current; pulse duration 200μs; intensity 'just perceptible') was applied for the 15 minutes prior to cuff inflation and during the 15 minutes of pain induction (electrodes placed over Erb's point and lateral to C6/7). The first TENS experiment investigated the influence of three different conditions (experimenter controlling TENS intensity; subject controlling TENS intensity; no TENS) using high frequency (100Hz) TENS. All subjects (n=12) were randomly exposed to the three testing conditions using a repeated measures design. A 2-way ANOVA with repeated measures on both factors showed no statistically significant effects ($p \geq 0.05$) on either VAS pain intensity or unpleasantness scores. The procedure was repeated with different subjects (n=12) using low frequency (5Hz) TENS. The results showed that mean pain scores were statistically significantly lower ($p \leq 0.05$) in the subject control condition than in the other two conditions (experimenter control and no TENS). A final experiment (n=12) compared VAS pain intensity and unpleasantness scores between the three conditions of; subject controlling 100Hz TENS, subject controlling 5Hz TENS and no TENS. The results demonstrated a trend for the 5Hz TENS condition to give lower mean pain scores than the other two conditions with both intensity ($p=0.239$) and unpleasantness scores ($p=0.110$). From the results and discussion it was suggested that the pain-relieving benefit of TENS was enhanced when the subjects were given control of the current intensity, especially when using low frequency TENS. The clinical implications of the results are discussed.

CONTENTS

Page No.

Figures and tables within text

APPENDICES

ABBREVIATIONS

ANOVA	Analysis of variance
DCS	Dorsal column stimulation
Hz	Hertz
MPQ	McGill Pain Questionnaire
μs	Microsecond (10^{-6})
mA	Milliampere (10^{-3})
ms	Millisecond (10^{-3})
mV	Millivolt (10^{-3})
MVC	Maximum voluntary contraction
PLOC	Pain Locus of Control Scale
TENS	Transcutaneous electrical nerve stimulation
VAS	Visual analogue scale
VRS	Verbal rating scale

CHAPTER 1 : PAIN MANAGEMENT AND THE ROLE OF TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION (TENS)

Pain has long since been identified and recognised by mankind and throughout history attempts have been made to explain and define the pain experience. Problems in the past have been encountered when the meaning of pain has been restricted to concepts which can be the subject of rigorous scientific analysis. These have included definitions of pain such as 'the physical adjunct of a protective reflex' (Sherrington, 1900, in Cervero, 1986) which ignore painful sensations not associated with protective mechanisms and abnormalities with the peripheral or central nervous system. The definition of pain used today by the International Association for the Study of Pain is;

> 'a sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage.' (Merskey, 1979)

The modern definition not only allows inclusion of those factors ignored in Sherrington's earlier definition of pain (Sherrington, 1900, in Cervero, 1986) but

also recognises that pain consists of both a physical and emotional component which interact with one another to contribute to the resultant experience.

The modern definition of pain is also reflected in the way in which pain is dealt in our society with the rising development of multidisciplinary pain clinics for the treatment of chronic pain and a more holistic approach to pain management programmes in general. It has now been well recognised by those working in the area of pain management that pain is a subjective experience and as such can be modified by a wide range of factors which will be identified and expanded on later in the thesis. The recognition of multiple influences on a person's pain has also meant that a greater number of treatment interventions are now available to the patient and their therapists. As well as surgical and drug oriented interventions patients now have available to them, either as adjunctive or alternative approaches, treatments such as acupuncture, cognitive-behavioural therapy or transcutaneous electrical nerve stimulation (TENS) (Fields, 1987).

It is on the last of these interventions, TENS, that this thesis is based. TENS has been established as a pain-relieving modality which operates through the stimulation of peripheral nerve fibres. It is used by both physiotherapists and physicians for the treatment of pain and is thought to be appropriate in a wide variety of clinical situations (Kahn, 1994). Physiotherapists play an important role within the multidisciplinary field of pain management and provide treatment such as exercise therapy, manipulation, massage and electrotherapy. TENS, within the component of electrotherapy, is a popular choice of modality and it has been

suggested that physiotherapists can modify a person's pain at peripheral, spinal, supraspinal and cortical level with the application of TENS (Walsh, 1991). In this way it is suggested that TENS not only relieves pain by physical means but also takes into account the multidimensional nature of pain and the effect that the modality has on cognitive processing. The multiple mechanisms of action of TENS are discussed in greater detail in Chapter 4.

The place of TENS within the science of pain management has become increasingly more prominent in the past two decades and this is reflected in part by the inclusion of TENS sessions at recent major international pain conferences such as those staged in Paris (7th World Congress on Pain, 1994) and Vancouver (8th World Congress on Pain, 1996). A chapter has also been dedicated to the modality in updated editions of the highly esteemed Textbook of Pain and papers appear on a regular basis in peer-reviewed journals such as *Pain* and the *British Journal of Anaesthesiology*.

TENS is used for a variety of different clinical pain conditions but its efficacy is still in question due to varied and often contradictory study outcomes. A major contributing factor to this state of confusion within study outcomes is due to the large number of TENS studies carried out without a rigorous study design. This point is highlighted by a number of recent TENS clinical review papers (Carroll, Tramer, McQuay, Nye and Moore, 1996; Carroll, Tramer, McQuay, Nye and Moore, 1997; Robinson, 1996) (see Chapter 6) which compared the outcomes of randomised controlled trials (RCTs) with less rigorously performed studies and, in

the instance of acute post-operative pain (Carroll et al, 1996), found that the studies which were not classed as RCTs produced a greater number of positive treatment outcomes than those in the RCT category (2 out of 17 RCTs produced a positive outcome compared with 17 out of 19 non RCTs). In this way the respective authors addressed methodological issues and assist the reader in understanding the relative value of TENS studies. The gold standard in clinical study design has been considered to be the RCT which, with its random allocation of treatment groups and inclusion of a control group is thought to increase the validity of the results and reduce the possibility of subjective experimenter bias (Ernst and Resch, 1996). For these reasons the majority of clinical studies reviewed in this thesis are selected on their basis to fulfil the criteria for a RCT. Reviewed clinical studies which do not meet the required standards to be classed as a RCT are commented on and the validity of the outcomes questioned in light of their shortcomings. A similar critique of possible methodological and design flaws are also highlighted in the laboratory based studies. The difference in study outcomes, however, can also be attributed to the wide number of variables between the studies including the selected current parameters of TENS, the environmental context of the treatment and the type of patients being used.

Review of clinical TENS studies (see Chapter 6) shows the diversity between methodologies, particularly with reference to control. Both acute and chronic pain are treated using TENS in many ways ranging from complete selection of parameters and operation of the TENS unit by the therapist (Conn, Marshall, Yadav, Daly and Jaffer, 1986; Lehmann, Russell, Spratt, Colby, Liu, Fairchild and

Christensen, 1986) to a more active role for the patient where they select their preferred parameters and are taught how to apply the modality themselves (Johnson, Ashton and Thompson, 1991a and 1991b; Smith, Egbert, Markowitz, Mosteller and Beecher, 1986). It has been recognised within the health care system that positive outcomes can be achieved from giving patients greater control of their pain-relief and through this the system of patient controlled analgesia (PCA) has evolved (Thomas, Heath, Rose and Flory, 1995). The proposed reason for the avocation of PCA has been that the rise in consumerism in modern day society has brought with it an increased desire for control in all aspects of life (Heath and Thomas, 1993). Heath and Thomas (1993) reported that when it comes to health, the doctor (or other care provider) is the equivalent of authority and needs to be an enabler rather than an absolute controller. In this sense, TENS can be viewed as a particularly useful treatment intervention for pain-relief as its portable design allows for increased patient involvement in their own management programme.

TENS is a relatively inexpensive modality, it is portable and has few contraindications to use (Walsh, 1997). It is therefore a treatment which can be used by patients for use in their own homes with the aim of managing their pain and subsequently reducing their reliance on medication and medical care (Ellis, 1995). The drive away from reliance on hospital-based treatment is also in line with recent NHS reforms to encourage primary health care within the community. The documented clinical use of TENS indicates that the modality is presently used under conditions of both patient and provider control and so in the present study

it is investigated whether pain measures are influenced by who controls the TENS current intensity.

The aim of the present study is to establish the influence that control of the current intensity has on the pain-relieving effects of TENS. There is a body of literature which has linked control with pain but to date the influence of control has not been investigated in relation to TENS. Walsh (1997), amongst other authors (Kahn, 1994; Low and Reed, 1990; Mannheimer, 1985), have stated that an advantage with TENS is that it is portable and so it is practical for patients to apply the modality themselves. The purpose of the present study, therefore, is to establish if whether giving the patient control of the TENS current intensity reduces their pain to a greater extent than if the therapist controls the current intensity. In this way the results of the present study can provide an indication as to how in-patient use of the modality can be adapted to improve treatment outcome and identify a factor which may influence outcome success with TENS when used by patients at home.

A major difficulty with carrying out a clinical trial is the large number of variables that must be controlled for if it is to fulfil the criteria required for a RCT. One way of reducing the number of external variables in a human pain study is to use an experimental model of pain induction (Gracely, 1994). It was, therefore, considered advantageous to adopt a laboratory based approach to the present study. The rationale for the selection of the pain induction procedure is explained later in the thesis (see Section 7.4.1), along with the chosen study design and the

methodology (see Section 7.4). The rationale is based on an extensive review of the relevant literature and this is encompassed in the succeeding six chapters. The aim of this substantial component of the thesis is to highlight the theoretical building blocks and the conceptual framework of the present study and to establish the current state of knowledge in these areas. The review of the literature, therefore, aims to identify gaps in the body of knowledge and carries implications for the experimental procedure of the present study. The six chapters attempt, systematically and in a logical order, to address each main topic area related to the present study and, briefly, the chapter topic areas read as follows;

Chapter 2 : The opening chapter of the review of literature introduces TENS as a pain-relieving modality. The chapter outlines the theory of how TENS operates and the various parameters it possesses which can alter the current characteristics.

Chapter 3 : This chapter provides a general introduction to the neurophysiology of the pain experience and highlights the differences between clinical and experimentally-induced pain.

Chapter 4 : This chapter is linked closely with Chapter 2 and outlines how TENS, through a number of different neural mechanisms, can modify a person's pain.

Chapter 5 : The psychological component of the pain experience is introduced in Chapters 2 and 3 and is then expanded on in this chapter. Variables which are thought to influence the psychological aspect of the pain response, in general and also specifically to TENS, are identified. The psychological variable of control, the crux of the present study, is defined in greater detail and its influence on pain addressed.

Chapter 6 : The efficacy of TENS is addressed in both the clinical and experimental setting. Reports of TENS' clinical efficacy include review papers of RCTs treating a variety of pain conditions. An overview is given of experimental pain induction techniques and a review is given of papers closely related to the present study.

Chapter 7 : Throughout the review of literature pain assessment scales are referred to and in this chapter greater detail is provided on the proposed criteria for ideal pain assessment. Three of the most commonly used scales in the reviewed studies are specifically addressed and the relative merits of each commented on.

Once the review of literature is fully covered the rationale for the present study is outlined. Each of the series of experiments in the present study is then documented in full, followed by the results and a discussion of the findings. The final two chapters in the thesis (Chapters 14 and 15) are dedicated to a global discussion of the results and their clinical inferences, respectively. In this way the limitations of the present experimental study are identified and their bearing on the clinical relevance of the results explored. The present study is contextualised within the science of pain management and recommendations are given for future research.

CHAPTER 2 : TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION (TENS)

2.1 : Introduction

Transcutaneous Electrical Nerve Stimulation (TENS) involves the transmission of electrical energy across the skin surface to the nervous system. The modality is used in the clinical setting primarily for pain-relief but recent research has also identified TENS' effects on circulation and autonomic function (reviewed in Walsh, 1997). This chapter outlines the historical perspective of TENS, as well as its theoretical principles and application and aims to provide the reader with background information about the modality used in the present study. The literature is based on a selection of publications in this area (Kahn, 1994; Low and Reed, 1990; Mannheimer, 1985; Scott, 1994; Walsh, 1997; Woolf and Thompson,

1994) and will not be referenced further unless additional information is added. In such instances specific references will be given.

Documented historical references to electricity as a pain-relieving modality begin in the year 46 A.D., several hundred years before the first written description of electrotherapy, when a Roman physician named Scripbonius Largus described how the electric stimulus for a Torpedo fish (electric eel) produced pain-relief for gout and headache (Kane and Taub, 1975). It was much later, in the 1700s, that electrotherapy was reintroduced with the use of electrostatic generators combined with Leyden jar condensers. This was recognised as a major breakthrough in the methodology of electrical stimulation as the device was able to both generate and store quantities of electric charge. The development of the battery during the nineteenth century further developed the advance of electrotherapy. John Wesley, the founder of Methodism, supported the advances of clinical electrotherapy activity and published one of the earliest texts detailing electrotherapy application in 1759. The medical profession met the new concepts with a degree of scepticism and, combined with conflicting clinical findings, electrotherapy declined towards the end of the 1800s.

In modern times, one of the first commercially available TENS units claimed to be a pain-controlling modality appeared in 1919. It was known as the Electreat and was battery powered. The pain-relieving efficacy of TENS was discovered almost by accident as the Electreat was used as a screening device for those people about

to undergo dorsal column stimulation (DCS), a procedure which involved the surgical implantation of battery-operated electrodes within the dorsal column of the spinal cord. Dr. Norman Shealy, developer of the Electreat, discovered that some of his patients responded more favourably to transcutaneous stimulation than to DCS and so a version of TENS was launched. There was, however, no accepted theoretical explanation as to how the effects were achieved.

The publication of the gate control theory of pain (discussed further in Chapter 3) by Melzack and Wall in 1965 provided this much needed theoretical explanation of pain-relief by electrotherapy and sparked renewed interest in the use of electrical stimulation for the control of pain. The theory proposed possible neurophysiological mechanisms for pain relief based on peripheral sensory stimulation and was supported further by Meyer and Fields (1972) who were among the first to report the efficacy of TENS in relieving chronic pain within the clinical setting. Our increased knowledge of neurophysiology and neuropharmacology since that period has been reflected in the prolific increase in pain research and since 1990 there has been an increase in publications in both clinical and experimental TENS studies.

An increase in scientific research has also meant an increase in the number of commercial TENS units available on the market. The increased technology benefits both the purchaser and user as specifically designed units can now be made which are portable and relatively inexpensive. The popularity of TENS as a

non-invasive and non-addictive modality was shown in a recent survey carried out by Pope, Mockett and Wright in 1995. The authors carried out a postal survey among 139 NHS physiotherapy departments throughout England to establish the use of electrotherapy modalities in clinical practice. The study received replies from 116 hospitals, representing a 83.5% return and 213 participants. TENS rated second on the list of electrotherapy modalities which were owned and, more importantly, used (n=201). TENS was surpassed only by ultrasound as the most frequently owned and used modality (n=212) and yet unpublished work by Walsh (1995, cited in Walsh, 1997) revealed that, in a survey of 181 Northern Ireland chartered physiotherapists, 79.1% were dissatisfied with the lack of stimulation guidelines for TENS. These findings suggested that clinicians, although reporting TENS as a popular modality, were unsure as to which variables were affecting pain perception and treatment outcome.

2.2 : Principles of electrical stimulation

Modern TENS machines, unlike the early Electreat which only offered alterable current intensity, possess a range of parameters which can change the current characteristics. These parameters will now be discussed in more detail under the following headings: waveform, pulse duration, pulse frequency and current intensity.

2.2.1 : Waveform

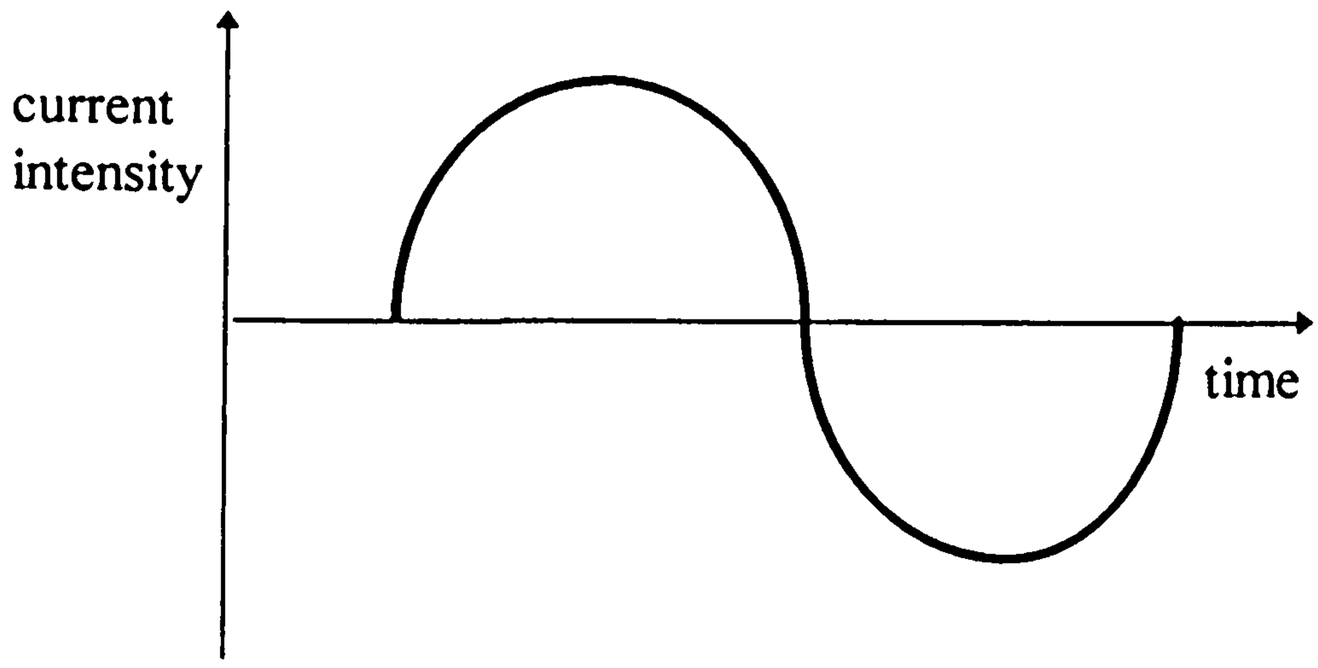
The waveform of a current refers to its shape on a graph showing amplitude (or intensity) against time. TENS is most accurately described as a pulsed current and as such can be uni-directional or alternating in nature. The latter possesses both positive and negative phases of current polarity and in most instances efforts are made to make both phases equal so that a net current component of zero is obtained. Current impedance at the electrode-skin interface and the resulting discomfort can be minimised when electrochemical changes are avoided and there is a zero charge flow.

Different shapes of waveform are also available but to date there has been little or no clear evidence of physiological benefit of any specific waveform over another.

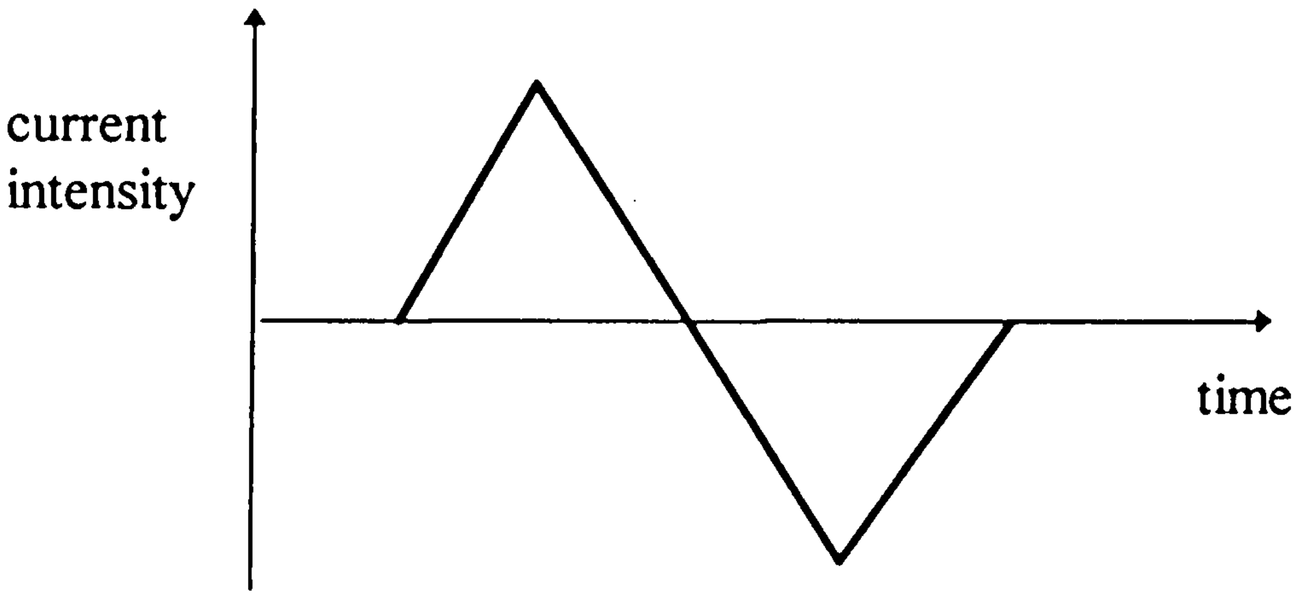
A study by Delitto and Rose (1986) investigated comparative patient comfort when using three different waveforms (sinusoidal, triangular and square - see figure 1) to produce a quadriceps contraction. Twenty-one healthy volunteers (sex and age not stated) were seated at an isokinetic dynamometer and asked to perform an isometric maximum voluntary contraction (MVC) of the left quadriceps femoris muscle group (knee positioned at 45 degrees of flexion). The MVC was repeated and the highest of the two torque recordings used in the study. A current intensity was then calculated for each of the current waveforms which was theoretically required to produce a knee extension torque level equal to 60% of the MVC. All three waveforms were then delivered in a randomised

Figure 1 : Different biphasic waveforms as shown on an oscilloscope tracing of the carrier current. (adapted from Delitto and Rose, 1986)

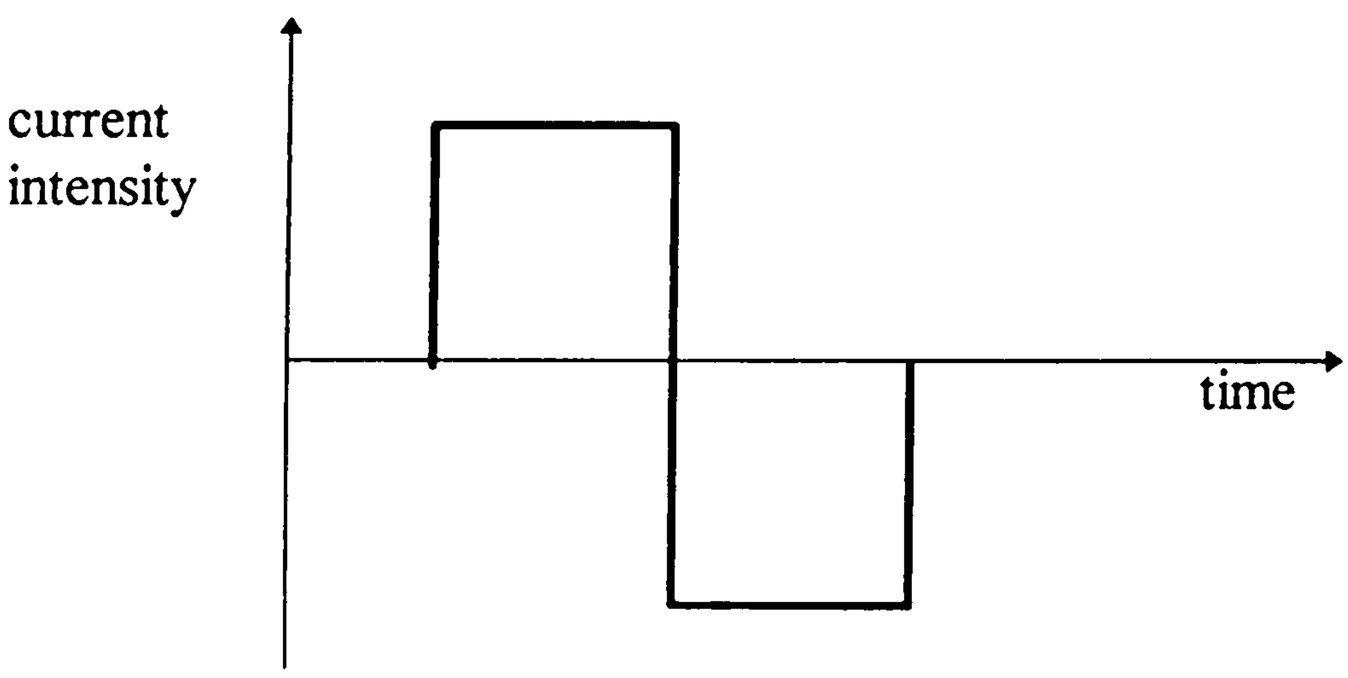
Sinusoidal



Sawtooth



Square



order three minutes apart with the same current characteristics of 2500 Hz pulse frequency and 10 ms pulse duration. The subjects rated their perceived discomfort following each muscle contraction on a 20 cm long visual analogue scale (VAS) labeled 'intolerable' at the left extreme and 'no discomfort' at the right.

A one-way analysis of variance (ANOVA) was conducted using the comfort scores for each waveform. The results showed no statistically significant difference between the waveforms ($F=1.57$; d.f.=2,38; p=NS). The authors concluded that it was impossible to differentiate whether the tolerance level was a result of differences in current characteristics specific to each stimulator or increased subject arousal levels at various contraction levels. A current intensity theoretically required to produce a knee extension torque equal to 60% of the MVC was used for each subject in the study. It was not stated in the paper how the required current intensity was calculated and it appears to be a potentially large source of error in the study. The methodology of the study chose to compare currents which produced a similar muscle torque which means that the actual current intensity levels were most probably different for each waveform. The actual current intensity selected for each waveform type was not stated and, therefore, any differences in perceived discomfort may have been due to variations in the amount of current being applied to each subject.

A later study comparing the effects of waveform on subject comfort during neuromuscular electrical stimulation was carried out by Baker, Bowman and

McNeal in 1988. Unlike previous research, such as that undertaken by Delitto and Rose (1986), the authors attempted to directly compare the various parameter combinations, therefore identifying those that caused least discomfort to the subjects. Healthy females (n=43; age range 21-35) were used for the study although the authors did not state how the sample was collected. The subjects were exposed to a variety of the six selected waveforms to either the wrist flexor/extensor muscle group (n=20) or to the quadriceps femoris muscle group (n=23) whilst seated in a standardised position. Testing took place over three days during which time a different pair of stimulus waveforms were directly compared with each other on separate days. Two electrodes were placed over the selected muscle group at the point of optimal muscle contraction and the locations marked for consistent placements in later sessions. Stimulus pairs were given for a period of 1.5 seconds each with a 15-18 second rest in between. A one minute rest was allowed between stimulus pairs and during each daily session the pairs were repeated at least ten times in a random order. The subject was asked to select the preferred waveform after exposure to each set of paired stimuli and was required to select the same waveform on at least four out of five occasions before being categorised as having a preference.

As in the previous study by Delitto and Rose (1986), an attempt to standardise the different current waveforms was made by calculating the current intensity needed to produce a muscle contraction in the selected muscle group ('fair +'). The authors reported that torque assessment was carried out through a ring strain-

gauge tensiometer but offered no explanation as to how a 'fair +' muscle contraction was determined. The procedure appears open to subjective bias and also lacks rigour as no attempt was made to standardise the other current characteristics such as pulse frequency or pulse duration. There was no evidence of statistical analysis of results and for this reason the authors were unable to identify the degree to which a waveform was preferred. The authors, however, did conclude that particular waveforms were perceived as being more comfortable in both the upper and lower limb. The clinical relevance of these findings remains questionable in light of the methodology.

2.2.2 : Pulse duration

The pulse duration of a current is the length of time of each individual electrical stimulus. The parameter is usually expressed in microseconds (μs) and in modern units the available frequency range is typically between 50μs and 400μs.

2.2.3 : Pulse frequency

The pulse frequency of a current indicates the number of stimuli being transmitted each second and is usually measured in Hertz (Hz). In the case of pulsed currents, the time for one stimulus is taken as the pulse width as well as the time elapsed between pulses. The range of current frequencies available for treatment varies between stimulators but Mannheimer and Lampe (1984) suggested that frequencies commonly used in clinical practice range from 4 Hz to 110 Hz. As well as current being supplied at a constant rate, stimuli can also be supplied in

trains with variable rest intervals. TENS in this form is more commonly referred to as burst TENS.

The effect of different frequency muscle stimulators on perceived discomfort was investigated by Grimby and Wigerstad-Lossing in 1989. Fifteen healthy female physiotherapists (age range 24-48 years; mean age 35 years) participated in the study and all were exposed to a high frequency sinusoidal wave stimulator (pulse frequency 2500Hz in trains of 50Hz frequency; pulse duration 10μs) and a lower frequency rectangular wave stimulator (pulse frequency 30Hz; pulse duration 0.3μs) in a randomised order. The subjects were seated in a standardised position at an isokinetic dynamometer while two carbon rubber electrodes were placed in precise anatomical positions over the right quadriceps femoris muscle group. Each subject was asked to perform a MVC three times and the maximum torque was recorded. This figure was then used to establish the current intensity required to produce a MVC using each stimulator. Testing involved subjects receiving thirty exposures to each stimulator (10 seconds on / 8 seconds off) and rating their discomfort after the 10th, 20th, and 30th stimulation periods.

The assessment tools used to measure discomfort were Borg's exponential 10-point scale (no other details regarding the scale were given in the paper) and a 7-point adjective scale in which the subjects had to choose two words that best described the stimulus sensation (adjectives were chosen from a previous pilot study carried out by the authors). A VAS (no details given) was also marked after

the 30th stimulation period. The results of the study showed a statistically significant correlation between the Borg and the VAS discomfort ratings (Spearman's rank correlation test: high frequency stimulator, $p<0.01$; low frequency stimulator, $p<0.05$). The Wilcoxon test showed no statistically significant difference between the stimulators in the level of discomfort they produced, although this may have been due to the other unstandardised properties of the stimulators such as the waveform, current intensity and pulse duration.

2.2.4 : Current intensity

The parameter of current intensity refers to the magnitude of current applied by the unit and is measured in milliamps (mA). Current is the flow of electric charge from the unit and the driving force required to move this electric charge is known as the voltage (measured in volts). Most TENS units are designed with either constant current or constant voltage output, the relationship between the two variables being provided by Ohm's Law;

$$V = I R$$

where V is the voltage, I is the electric charge, and R is a resistance to the electric charge such as the skin's surface. A unit that supplies a constant current output will alter the voltage intensity, within limits, as the resistance changes. The reverse holds true for the constant voltage unit and therefore care should be taken to

maintain a consistent electrode-skin interface so that potentially painful increases in current intensity are avoided.

There is still a great deal of controversy among clinicians as to the ideal current intensity for TENS administration but it is agreed that current intensity is best rated subjectively by the person receiving TENS rather than by a milliamp or voltage readout from the unit. Authors recommend current intensities ranging from 'just detectable' to 'just tolerable' and even sub threshold currents have been used in clinical practice. The most common level of current, however, used in clinical practice is one which is perceived by the patient to be strong but comfortable (Frampton, 1996). Lehmann, Russell, Spratt, Colby, Liu, Fairchild and Christensen (1986) categorised 53 patients with chronic low back pain (>3 months) into 3 groups based on previous back surgery. The patients were then randomly assigned to 1 of 3 treatment groups which consisted of TENS (n=18), placebo TENS (dead battery) (n=18) and electroacupuncture (n=17). The treatment programme consisted of 3 weeks in-patient care during which time the patients received TENS (frequency 60Hz; pulse duration 40μs; sub threshold current intensity) or placebo TENS daily except for weekends. The duration of each treatment session was not stated in the paper. Patients in the electroacupuncture group received treatment twice a week at a frequency of 2-4Hz and a high current intensity at pain tolerance level.

Patients were asked to rate their general and peak pain on a 10cm long VAS periodically but it is not clear how long apart these assessments took place or when they were relative to receiving treatment. An analysis of variance showed a statistically significant treatment effect, with respect to time ($F=2.99$; d.f.=4,91; $p<0.03$), but there was no statistically significant difference between the groups' pain scores between admission and discharge. It is difficult to compare the two TENS groups with the group receiving electroacupuncture as the treatment regimes were so dissimilar. The results, however, did suggest that in this particular study sub threshold current intensity in conjunction with the selected parameters was no more effective in reducing pain than placebo TENS. This result is hardly surprising as a subthreshold current would be theoretically incapable of stimulating even large diameter afferent fibres and would therefore be no different from a placebo treatment.

2.3 : Modes of TENS

TENS can be classified into different modes depending on the selected parameter combination of pulse duration, current frequency and current intensity. The two most common modes of TENS currently in use in clinical practice are called conventional TENS and acupuncture-like TENS. The former is typically a high frequency (≥100Hz) with a low current intensity and usually a short pulse duration (50-80μs). Acupuncture-like TENS shares none of the conventional TENS properties and instead is typically of low frequency (1-4Hz), a high enough intensity to produce visible muscle contractions and possesses a long pulse

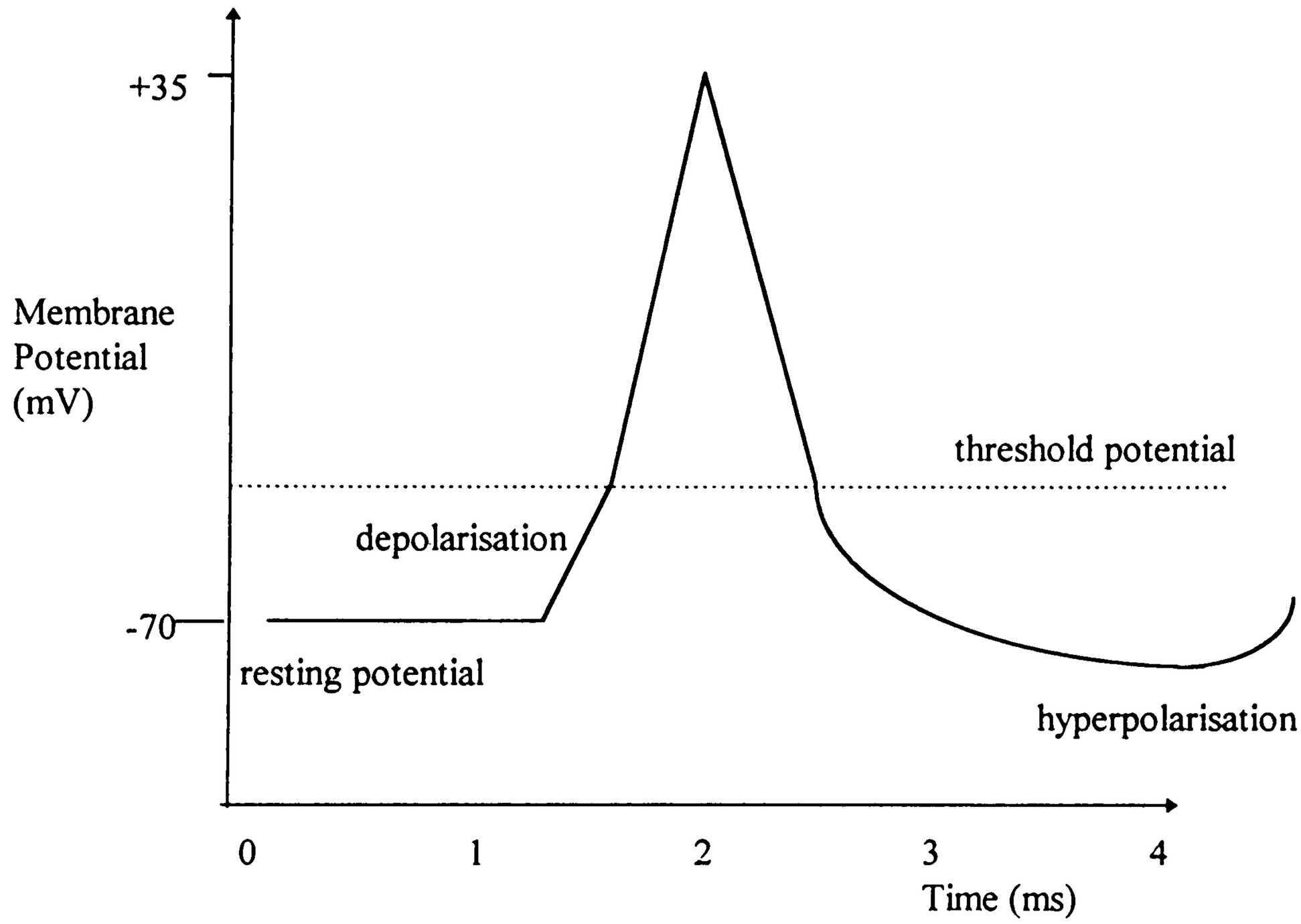
duration (about 200μs). A variation of both modes is burst TENS which, by definition, has high frequency trains of pulses delivered at a low frequency.

2.4 : Nerve stimulation by TENS

Nerve fibres in a resting state have a potential or charge difference between the intracellular fluid and the extracellular fluid. The resting potential is approximately -70mV, the minus sign indicating that the inside of the cell has a negative charge relative to the exterior. The unequal distribution of charged ions across the cell membrane in the nerve cells forms the basis for the generation of action potentials and these can be initiated by the transient reversal of the membrane potential (depolarisation) with an electric pulse. The electrical stimulus allows the opening of voltage-activated ionic channels in the cell membrane and subsequent movement of ions down concentration gradients. As the stimulus is increased, the potential difference across the cell membrane decreases until the critical threshold level is reached. Once threshold is reached, the stimulus will lead to the automatic generation of an action potential (Guyton, 1991) (see Figure 2).

The minimum amount of electrical current required to reach threshold is known as the rheobase. Greater amounts of current do not result in larger action potentials and any increased sensory effects which may be experienced with higher current intensities are due to a larger number of fibres being stimulated. An action potential only occurs if threshold is reached and therefore nerve stimulation is referred to as an all-or-none response. While a nerve fibre is depolarised from a

Figure 2 : Generation of an action potential. (not drawn to scale) (adapted from Walsh, 1997)



preceding action potential, a second action potential cannot be generated. An action potential returns to its resting value in about 1 millisecond and during this time no stimulus, however large, will initiate another action potential. This time span is known as the absolute refractory period and is followed by another time span known as the relative refractory period. The relative refractory period represents a residual inactivation of the ionic channels and a larger stimulus than normal is required during this time span to reach threshold.

The refractory period of a nerve fibre is inversely proportional to its conduction velocity which, in turn, is determined primarily by two anatomical features. The first is nerve diameter with larger diameter nerves offering less electrical resistance and, therefore, greater conduction velocities. The second feature is the presence of myelin on the nerve fibre. The myelin is wrapped around the nerve fibre and is interrupted at intervals along its length at junctions called nodes of Ranvier. The myelin not only insulates the fibre but allows the action potential to be conducted quickly from node to node; a process referred to as saltatory conduction. The increased diameter of a nerve and presence of myelin, therefore, alter the refractory periods of individual nerves and results in mixed bundles of fibres possessing different rheobases. The structure of particular nerve fibres will be discussed in Chapter 3.

It is important to note that electrical activity cannot be transferred directly from one nerve to another and requires a chemical substance (neurotransmitter) to be

released into the junction (synapse) between the adjacent nerves. The neurotransmitter is released from the end terminal membrane of the active nerve in a response to depolaristion. Many different types of neurotransmitter act in the nervous system and include acetylcholine, noradrenaline and substance P. Once released into the synapse, the neurotransmitter then binds itself to the receptor sites of the other nerve involved. The effect which the neurotransmitter has on the receiving nerve is dependent on the nature of both the neurotransmitter and the receptors. The resultant effect can be due to activity at either the pre-synaptic or post-synaptic membrane but there are basically two forms of synapse; (1) the excitatory synapse and (2) the inhibitory synapse. The former initiates depolarisation which in turn helps to generate an action potential in the receiving nerve. The latter brings about hyperpolarisation and resists the generation of an action potential in a neighbouring nerve cell. It is the combination of these two types of synapse which results in the complex interaction of neural pathways and pain perception (Bond, 1984; Guyton, 1991) (discussed further in Chapter 3).

In order to stimulate a nerve, the stimulus has to be of sufficient intensity and pulse duration to depolarise the nerve membrane. Strength-duration curves are graphs of the current intensity needed to generate a nerve impulse plotted against the duration of the pulses (see Figure 3a). Stimuli which have not reached threshold will have parameter combinations that fall left of the strength-duration curve and are therefore unable to generate an action potential. Figure 3a indicates the response of sensory, motor and nociceptive fibres to an electrical stimulus and

Figure 3a : Strength-Duration curve for different types of nerve fibre. (adapted from Walsh, 1997)

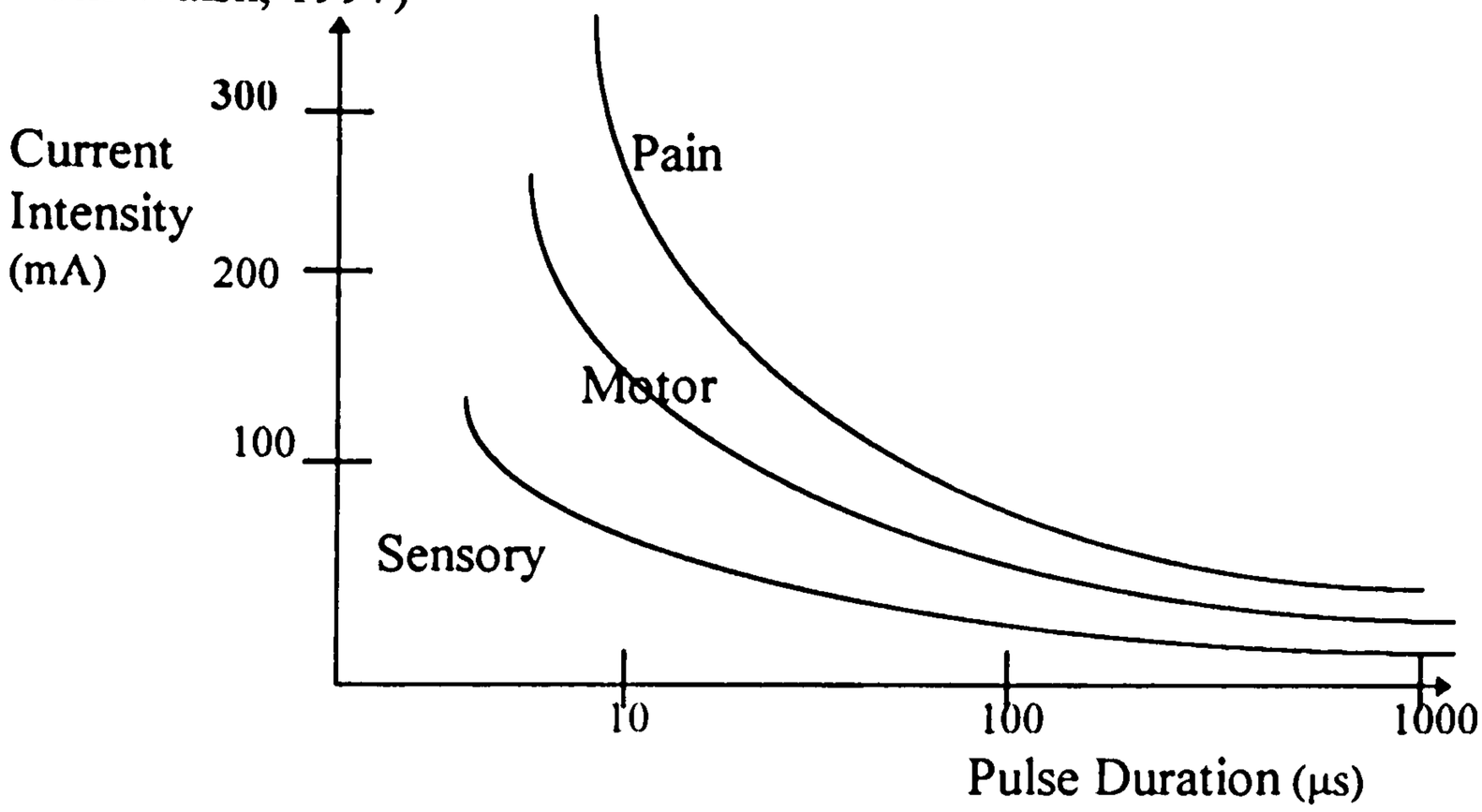


Figure 3b : Relationship between frequency and current intensity. (adapted from Woolf and Thompson, 1994)

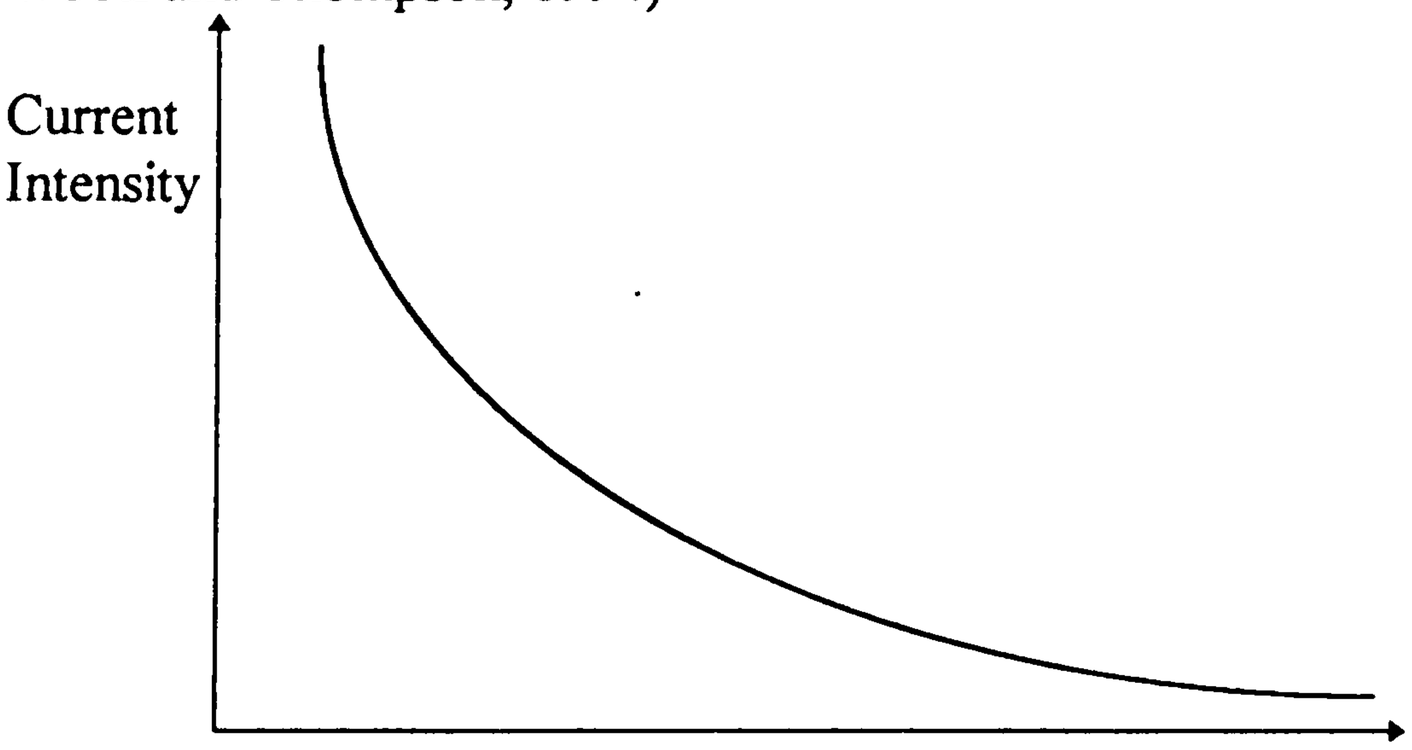
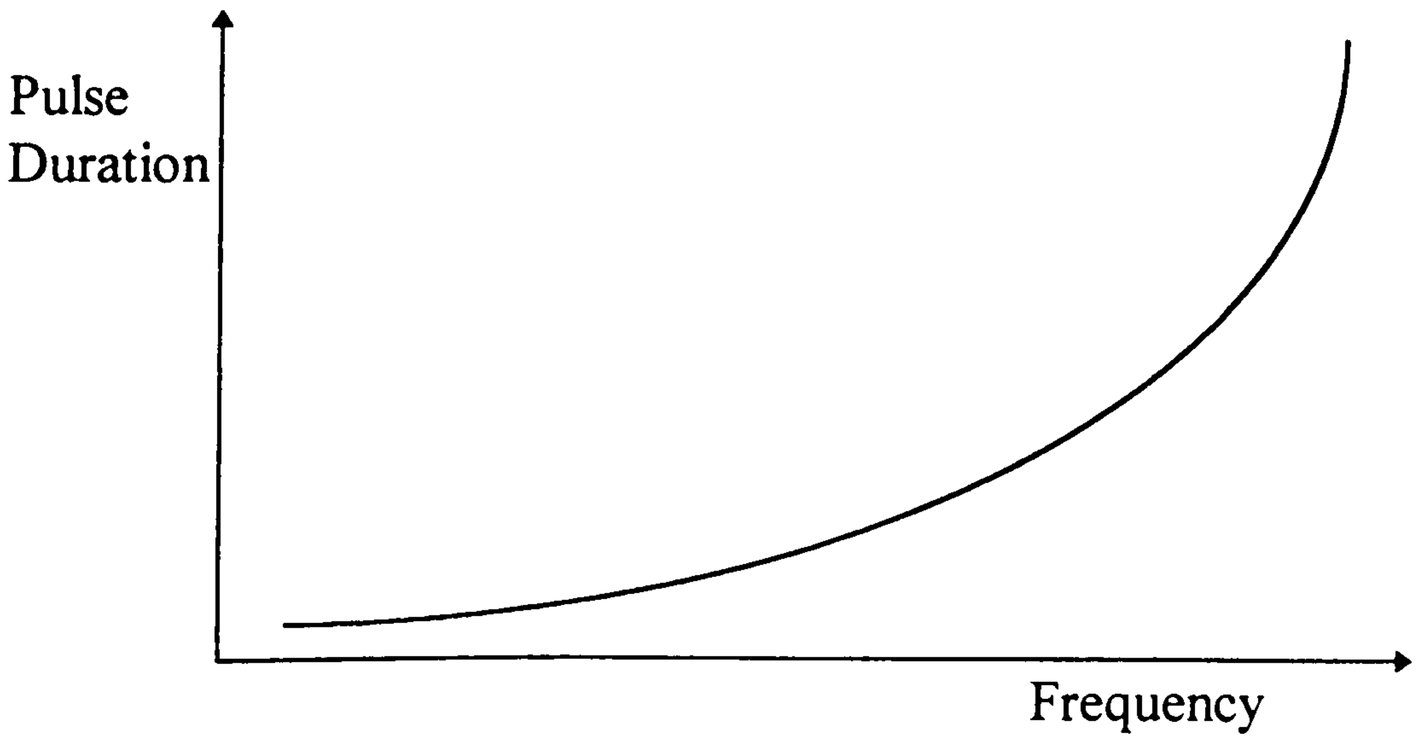


Figure 3c : Relationship between frequency and pulse duration. (adapted from Woolf and Thompson, 1994)



shows that if a mixed nerve is stimulated the person will first report a non-painful skin sensation, followed by muscle contractions and finally pain.

The relationship between current intensity and pulse duration is such that at low pulse durations, a greater intensity of current is required to produce an action potential. This remains true until the rheobase is achieved, at which point an increase in pulse duration makes no difference to the nerve's ability to generate an action potential.

There is also a relationship between current frequency and the two parameters already mentioned (see figures 3b and 3c). The relationships shown in Figures 3b and 3c are based on theoretical electrical principles of pulse charge and allows parameters to be calculated if not already pre-determined by the TENS unit.

2.5 : TENS application

The following section is concerned with the practical issues regarding the use of TENS, including the equipment needed and its application.

2.5.1 : Electrodes

TENS aims to deliver electrical current to a pair of electrodes in order to excite afferent nerve fibres. The current must be sufficient to stimulate the nerve in a controllable manner without causing any damage to the skin. A number of different electrode types are now available, the most common material being a

carbon-silicone combination. This material combination has the advantages of being strong and inert, as well as being able to follow the shape of the body's contours. The main disadvantage that the carbon-silicone electrodes possess is that they require adhesive tape to secure them to the skin. Self-adhesive electrodes are now available for use with TENS and can be either disposable or reusable.

A transmission medium is needed to pass current from the electrode to the skin. The impedance of the skin and tissues below the electrodes is non-homogenous and localised areas of low impedance are produced by perspiration. Various conductive electrolyte gels have been designed for the purpose of current transmission and without such gel TENS current can produce thermal damage to the corneal layer of the skin. Electrode size determines the current density flowing to the underlying tissues with smaller electrodes giving a higher localised current density at the point of skin contact. Woolf and Thompson (1994) reported that the current density required for TENS was typically 1-5 mA/cm^2 and suggested that electrodes should be at least 4 cm^2 in size to prevent skin irritation.

2.5.2 : Electrode placement

The question of ideal electrode placement remains a controversial topic in TENS, with no one method reported as being consistently more successful in reducing pain. Techniques which are most frequently used are dermatone levels, acupuncture trigger points, peripheral nerve courses and the site of pain. Jones,

Lee, Holzberger and Jones (1990) compared the pain-relieving efficacy of TENS using different electrode placements in twelve elective post-cholecystectomy patients (2 male, 10 female; age range 16-70). All received the same relative amount of analgesia during surgery and on post-operative day one the patients were visited once in the morning and again in the afternoon (3 hours apart). On each occasion TENS (frequency 99Hz; pulse duration 175μs; current intensity 'maximum without discomfort') was applied for 20 minutes with electrode placement dependent on which group the patient had been randomly assigned to; one group (n=6) had the electrodes applied over the acupuncture points for the gall bladder, while the other group (n=6) had the two electrodes placed para-incisionally. The group which received acupuncture point TENS in the morning received para-incisional placement of the electrodes in the afternoon and vice versa. The whole procedure was repeated on the second day post-operatively but in the reverse order.

During all four TENS sessions patients were asked to rate their pain on a 10cm long VAS before, immediately after, and 30 minutes post TENS treatment. Analysis of the results using a two-tailed t-test showed a statistically significant improvement in pain-relief immediately and 30 minutes after TENS treatment. This treatment was irrespective of electrode placement. The time of day which surgery was performed in each case was not stated and so it is difficult to establish if pain rating scores were dependent on the TENS stimulation or the effects of

intravenous analgesia. It would appear appropriate to try a number of different electrode placements in order to establish optimal placement for pain-relief.

2.5.3 : Duration of TENS treatment

The stimulation of peripheral nerves by TENS is indiscriminate and all afferent nerves with a particular threshold will be activated by an electrical stimulus if it exceeds the threshold value. Pain-relief from TENS, therefore, is a result of activation of both rapidly and slowly adapting afferent nerves because they possess similar electrical thresholds. The mechanisms on which TENS are proposed to work will be discussed fully in Chapters 3 and 4 but the basis of pain-relief by TENS has been thought to be dependent on its mode of application. The mechanism of action of conventional TENS is considered to bring about a decrease in pain perception relatively quickly (less than 10 minutes) and continues for about 30 minutes (Eriksson, Sjolund and Nielzen, 1979; Sjolund and Eriksson, 1979). The pain-relieving action of acupuncture-like TENS, on the other hand, is produced after approximately 15-30 minutes of stimulation and has a longer duration (several hours) of action once the stimulation has been removed (Eriksson et al, 1979; Sjolund and Eriksson, 1979).

Textbook authors remain indecisive as to the optimal length of treatment time with TENS, with time spans of 20 minutes to periods of up to 8 hours being advised. It appears, therefore, that the treatment time of TENS may be dependent

on the type of pain being addressed and can be applied as long as necessary provided no skin irritation or other side-effects are noted.

2.5.4 : Contraindications with TENS

As with any electrotherapy modality, it is necessary to assess the user for any contraindications to the modality before beginning treatment. TENS has relatively few contraindications, most of which are common sense.

(1) TENS should not be used with those who have a cardiac pacemaker

(2) Electrodes should not be placed over the pharyngeal region or the carotid sinus

(3) Electrodes should not be placed over open wounds or any form of skin lesion

(4) TENS should not be used with those who have an allergic reaction to the tape or gel

(5) Electrodes should not be placed over the pregnant uterus in the third trimester of pregnancy

(6) Finally, TENS should not be used with those that are unable to comprehend the use of the modality.

2.6 : Conclusions

(1) TENS is a popular electrotherapy modality used in the clinical setting primarily for pain-relief.

(2) TENS possesses a number of parameters, all of which can alter the current characteristics and the resultant sensation of the person receiving the treatment.

CHAPTER 3 : ANATOMICAL AND PHYSIOLOGICAL BASES FOR PAIN

3.1 : Introduction

Pain is a unique experience which can be classified into two major categories. The first category is acute pain which is characteristically triggered by harmful or potentially harmful (noxious) stimuli and is a necessary protective mechanism against further damage. The second category is chronic pain and is sometimes defined as a pain that persists a month beyond the usual course of an acute injury or disease (Cailliet, 1993). Chronic pain does not always serve a useful purpose and can become an abnormal and self-sustaining noxious agent in its own right. It is therefore important to differentiate between acute physiological pain and that which occurs when there is malfunctioning of the nervous system (pain in the absence of noxious stimuli).

There is also a difference between acute physiological pain and transient pain which is induced experimentally. Such is the case in the present study. With transient pain there is no, or minimal, tissue damage and the pain sensation remains only a short time after the removal of the painful stimulus (Johnson, 1997). Acute clinical pain, on the other hand, is associated with tissue damage and its duration is expected to be related to the rate of tissue healing (Johnson, 1997). The tissue damage involved with acute clinical pain contributes to the body's mechanisms which serve to protect the injured site from further damage. Clinical symptoms of these protective mechanisms include exaggerated pain (hyperalgesia) and tenderness (allodynia) and occur as a result of increased sensitivity of the nociceptive system to afferent input (Johnson, 1997). Although transient experimental pain and acute clinical pain are physiologically different in that there is an absence of clinical symptoms in the former, they are both considered to be physiologically normal in their neural responses to noxious stimuli. This is different from the chronic pain situation where pain can be registered in the absence of a noxious stimulus. For the purposes of this thesis the normal physiological situation will be discussed.

Before expanding on the subject, a distinction should be made between the terms nociception and pain. The former relates to the activation of the nervous system in response to noxious stimuli while the latter is concerned with the perception of this information by the cerebral cortex. The perception of pain is therefore a subjective experience which is basically a direct reflection of the nervous system's active processing of the neural input it has received. This processing can occur at

both spinal and supraspinal levels and can involve activity in a number of different pathways, explaining the multidimensional (physical and emotional) nature of the pain sensation. The pain processing system can be thought of in 3 stages interacting with each other; (1) peripheral nociception, (2) spinal cord modulation, and (3) higher centre, in particular cortical, involvement.

3.2 : Peripheral nociception

Nociceptors are primary afferent nerves with peripheral terminals which respond selectively, and preferentially, to noxious stimuli (Sherrington 1906, in Meyer, Campbell and Raja, 1994). Nociceptors respond to a range of stimuli, including those applied externally (e.g. intense levels of mechanical or thermal stimulation as well as extreme levels of light or noise) and also to physical and chemical products of internal tissue damage (nociceptors are receptive to chemical changes in the body such as increased levels of bradykinin, serotonin and substance P which are produced during tissue inflammation) (Fields, 1987; Meyer et al, 1994). The main functions of primary afferent nociceptors are transduction (the conversion of one type of energy i.e. chemical, mechanical or thermal to electrochemical nerve impulses) and transmission (the relaying of afferent impulse information onwards to pathways within the central nervous system which results in the sensation of pain). Nociceptors are generally 'free' nerve endings and are located anywhere in the body, superficially or deeply, where pain can be registered (Charman, 1989; Meyer et al, 1994). Different classes of nociceptors have been identified primarily from cutaneous receptor research. This is due to the fact that the skin is densely innervated and it is relatively easy to apply controlled

noxious stimuli to it. Findings from cutaneous studies have provided evidence to support that Aδ and C fibres are the afferents involved in nociception (Fields, 1987; Jessell and Kelly, 1991; Meyer et al, 1994).

Afferent fibres have been classified according to their diameter and conduction velocity, with these physical characteristics contributing to the variation in pain sensation that each nociceptor type produces (Lee and Warren, in Walsh, 1991). C fibres account for approximately three quarters of the total number of nociceptive afferents and have been found to respond to noxious levels of thermal, mechanical, and chemical stimuli in different combinations (Fields, 1987; Meyer et al, 1994). The fibres are small in diameter, unmyelinated and have a slow conduction velocity of between 0.5 - 2 metres per second (Walsh, 1991). Early studies by Torebjork and Hallin (1973, 1974) used selective stimulation of C fibres to show that their activity was associated with a prolonged burning sensation which had a slightly delayed onset (sometimes referred to as 'second pain').

'First pain' has been attributed to Aδ fibre stimulation and has been described as "an early sharp pricking sensation" (Fields, 1987). Aδ nociceptors fall into two categories (Aδ mechanical and Aδ thermal), which respond preferentially to noxious levels of mechanical and heat / cold stimuli respectively (Meyer et al, 1994). Both types of receptor, as well as the C fibre class, experience a decrease in threshold value as they are repeatedly exposed to noxious stimuli - a property known as sensitisation (Cailliet, 1993; Jessell and Kelly, 1991). Aδ fibres are

myelinated, slightly larger in diameter than C fibres and have a conduction velocity of between 12-30 metres per second (Walsh, 1991). The conduction velocities of both nociceptive classes are significantly lower than the large-diameter myelinated Aβ fibres which are stimulated by non-noxious mechanical stimuli and can transmit afferent information at speeds of up to 100 metres per second (Walsh, 1991). The three types of nociceptor which have been identified each contribute uniquely to the resultant pain sensation (Meyer et al, 1994). There is no simple relationship between activity in an afferent nociceptor and the perceptual experience. The pain experience is a result of all the afferent impulses received from all the various receptors and their modulation within the central nervous system (Cailliet, 1993; Fields, 1987; Jessell and Kelly, 1991).

3.3 : Spinal cord modulation

Following noxious stimulation impulses are conducted along different nerve fibres and enter the spinal cord. The majority are thought to enter by way of the dorsal roots, but some also proceed to the dorsal horn via the ventral roots (Cailliet, 1993). Their sites of termination in the spinal cord include the dorsal horns of the grey matter (Bond, 1984). The spinal cord grey matter is arranged in a laminar organisation and divided into ten layers (I - X) on the basis of each layer's physical characteristics. The synaptic endings of the C fibres are thought to terminate in the two most superficial layers (laminae I and II), while most projections of Aδ afferents terminate in lamina I or project deeper to lamina V (Fields, 1987).

Nociceptive afferent fibres synapse generally on interneurones within the superficial laminae and the information is then relayed to projection neurones which may be in lamina I or deeper laminae (Lima, 1997). Examples of cells which respond to nociceptive input in the dorsal horn are (1) nociceptive specific (NS) neurones (mainly in lamina I) which respond exclusively to stimulation within a noxious range and (2) wide dynamic range (WDR) neurones (mainly laminae III and IV) which respond to both noxious and non-noxious stimuli (Garrison and Foreman, 1994; Lima, 1997). The dorsal horn therefore represents a complex circuit of neurones that not only receives and transmits nociceptive input but also allows a high degree of sensory processing and interaction of noxious and non-noxious inputs. This local processing is a result of a combination of excitatory and inhibitory influences from a combination of sources. These include the periphery, local interneurones and axons descending from the brain stem in turn influenced by higher centres including the cerebral cortex (Cailliet, 1993; Charman, 1989; Steedman, 1989). The relationship between noxious afferent input arriving at the spinal cord and the output is therefore complicated and variable, with considerable opportunity for modulation at this stage within the central nervous system.

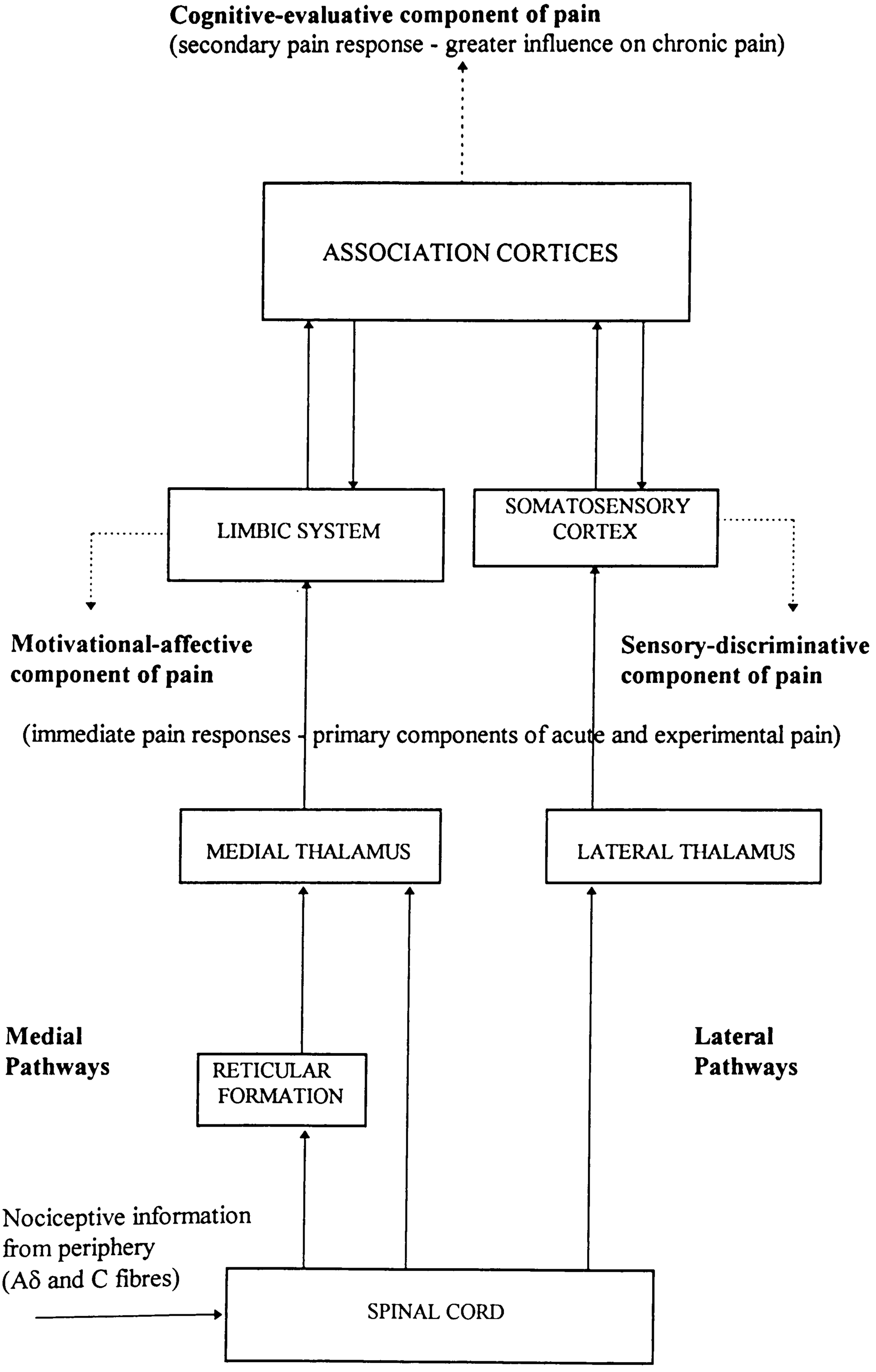
Lima (1997) suggested that the activation of certain cell types within the spinal cord, with particular reference to lamina I, may follow a pattern of input distribution. The author hypothesised that the distribution of variable amounts of nociceptive input through each cell type may be part of a tuning system which contributes to the qualitative characteristics of the stimulus but stressed that more

research into the area was required. This concept has important implications for sensory perception as once nociceptive impulses have been modulated within the spinal cord they either pass directly to interneurones which act on the motor or autonomic system, or they are transmitted to neurones whose axons make up ascending systems to the brain stem and higher centres (Fields, 1987; Guilbaud, Bernard and Besson, 1994).

3.4 : Higher centre involvement

The primary pathways for transmission of nociceptive information to the higher centres can be considered as parts of two main systems - the lateral and medial systems (Fields, 1987; Guilbaud et al, 1994; Jessell and Kelly, 1991). The lateral system includes the neospinothalamic tract (nSTT), dorsal column tract (DCT) and the spinocervical tract (SCT) which project through lateral thalamic nuclei. The DCT and nSTT are primarily concerned with non-noxious information but are also activated by noxious stimuli. All these tracts have relatively large diameter fibres (primarily Aδ fibres) with few synaptic junctions and therefore have a quick conduction velocity. There is evidence to suggest that the neospinothalamic tract within the lateral system is concerned with rapid transmission of nociceptive input which contains information about the physical qualities of the stimulus. This information can then be facilitated or inhibited by cognitive influences (Bond, 1984; Guilbaud et al, 1994; Jessell and Kelly, 1991) (see Figure 4).

Figure 4 : Simplified diagram of spinal and supraspinal pain pathways.



The medial ascending system consists of the paleospinothalamic tract (pSTT), the spinoreticular tract (SRT), the spinomesencephalic tract (SMT) and the multisynaptic ascending systems (MAS) which project through medial thalamic nuclei (Cailliet, 1993; Jessell and Kelly, 1991). The fibres which make up these tracts are thinner than those in the lateral system (primarily C fibres) and have many more synaptic connections and for this reason impulses passing in this system are slower in reaching the higher centres than those in the lateral system. It is thought that the medial tracts play a role in transmitting information about the motivational-affective component of the pain response (Guilbaud et al, 1994) (see Figure 4).

The properties which are perceived in response to a pain stimulus are dependent on the target sites of each of the neural pathways. The lateral system is quite specific regarding its higher centre destination, terminating in the primary somatosensory cortex (Jessell and Kelly, 1991; Lima, 1997). This area of the cerebral cortex is concerned with the physical characteristics of the stimulus and is therefore able to provide information about the stimulus intensity, frequency and duration - the sensory-discriminative component of pain (Jessell and Kelly, 1991). The medial system, on the other hand, has a wider range of destinations which include the basal ganglia, limbic cortical areas such as the cingulate gyrus and the pre-frontal cortex (Fields, 1987; Guilbaud et al, 1994; Jessell and Kelly, 1991; Lima, 1997). Some of these areas are not exclusively involved in nociceptive processing and so it has been suggested that the medial system is also responsible

for part of a non-specific arousal system (Jessell and Kelly, 1991; Guilbaud et al, 1994). Areas such as the limbic system and the temporal lobe are under the influence of attentional mechanisms and so, as well as giving the pain stimulus affective component, they are also subject to modulation according to the emotional context in which the stimulus is delivered (Lima, 1997). This has important implications for pain assessment as it suggests that a person's immediate motivational-affective response to a painful stimulus is influenced directly by attentional mechanisms. In addition, activation of motivational-affective target sites can result in descending inhibition of noxious input from the cingulate gyrus and implies that 1st stage pain perception (intensity and unpleasantness) can be modulated at both thalamic (brainstem) and spinal cord levels.

This recent research has therefore provided a detailed neurophysiological rationale for the multi-dimensional model of the pain experience first elaborated on by Melzack and Casey in 1968. The authors proposed that there were three main components of pain: sensory-discriminative (physical component of pain), motivational-affective (emotional component of pain), and cognitive-evaluative (perception of pain based on cognitive processing) and that each were served by a particular physiological system which involved different areas of the supraspinal anatomy. This pain model implied that the sensory-discriminative and motivational-affective components of pain acted through two separate, parallel systems but more recent research has indicated that the two systems interact with

each other and have the ability to relay information to each other (Fields, 1987; Jessell and Kelly, 1991; Jones, 1997; Lima, 1997).

Pain perception can therefore be considered as occurring in two stages. The initial stage is the immediate response to the pain stimulus and is composed of primarily the sensory-discriminative and motivational-affective components (Jones, 1997; Price and Harkins, 1992; Wade, Dougherty, Archer and Price, 1996). These are mediated at the level of termination of ascending systems within the cortex - principally in the primary somatosensory and limbic areas respectively. The pain components of the 1st stage of pain perception (sensory-discriminative and motivational-affective) are though to play a larger role in cases of acute or experimental pain (Price and Harkins, 1992). The second phase of interactions in cortical association areas, which involve further stages of cognitive interpretation of the initial pain perception and places it into an emotional context (cognitive-evaluative component of pain), plays a larger role in chronic pain (e.g. frustration and anger because of being unable to go to work) (Price and Harkins, 1992). This has important implications for pain assessment as it demands distinction between different types of pain (i.e. acute, chronic or experimental) and also careful consideration of the times at which the pain measures are taken.

Cognitive processing plays an important role in the pain experience and mental activities in cortical regions such as the frontal, temporal and parietal lobes influence pain through the corticofugal and subcortical descending pathways (see Figure 4). These descending influences can act on both sensory-discriminative and

motivational-affective components selectively and also, through connections in brainstem areas, modulate noxious input within the dorsal horn before it reaches the ascending pathways (Bond, 1984; Fields, 1987; Jessell and Kelly, 1991). In this way pain perception can be viewed as being the result of complex neurophysiological interactions at spinal, brainstem and cortical levels and is always a unique experience.

3.5 : Conclusions

(1) Pain perception is the conscious response to a noxious stimulus which can be modulated at spinal, brainstem and cortical levels.

(2) Neurophysiological evidence supports a multi-dimensional response to pain consisting of sensory-discriminative, motivational-affective and cognitive-evaluative components acting in separate but interacting systems within the central nervous system.

(3) Pain perception can be thought of as occurring in 2 stages; the 1st stage consisting primarily of the sensory-discriminative and motivational-affective components and the 2nd stage, the cognitive-evaluative component.

(4) Based on (2) and (3) above, pain assessment outcomes are therefore dependent on the component of pain being assessed and the timing of the assessment.

CHAPTER 4 : PAIN MECHANISMS AND THE RATIONALE FOR THE USE OF TENS

4.1 : Introduction

Much debate has arisen over the years regarding the rationale for the clinical use of TENS for pain-relief, with the literature supporting evidence for multiple mechanisms of action (Eriksson et al, 1979; Garrison and Foreman, 1994; Hughes, Lichstein, Whitlock and Harker, 1984). The aim of this chapter is to identify to the reader the underlying theories which are considered to explain why TENS reduces pain. Major differences in neurophysiological action of the proposed central mechanisms are thought to be associated with the chosen parameters, namely the intensity and frequency of the currents supplied (Hughes et al, 1984; Levin and Hui-Chan, 1993; Sjolund and Eriksson, 1979). Two main categories of TENS have already been identified in Section 2.3 and they are characterised as being either high frequency / low intensity (conventional TENS)

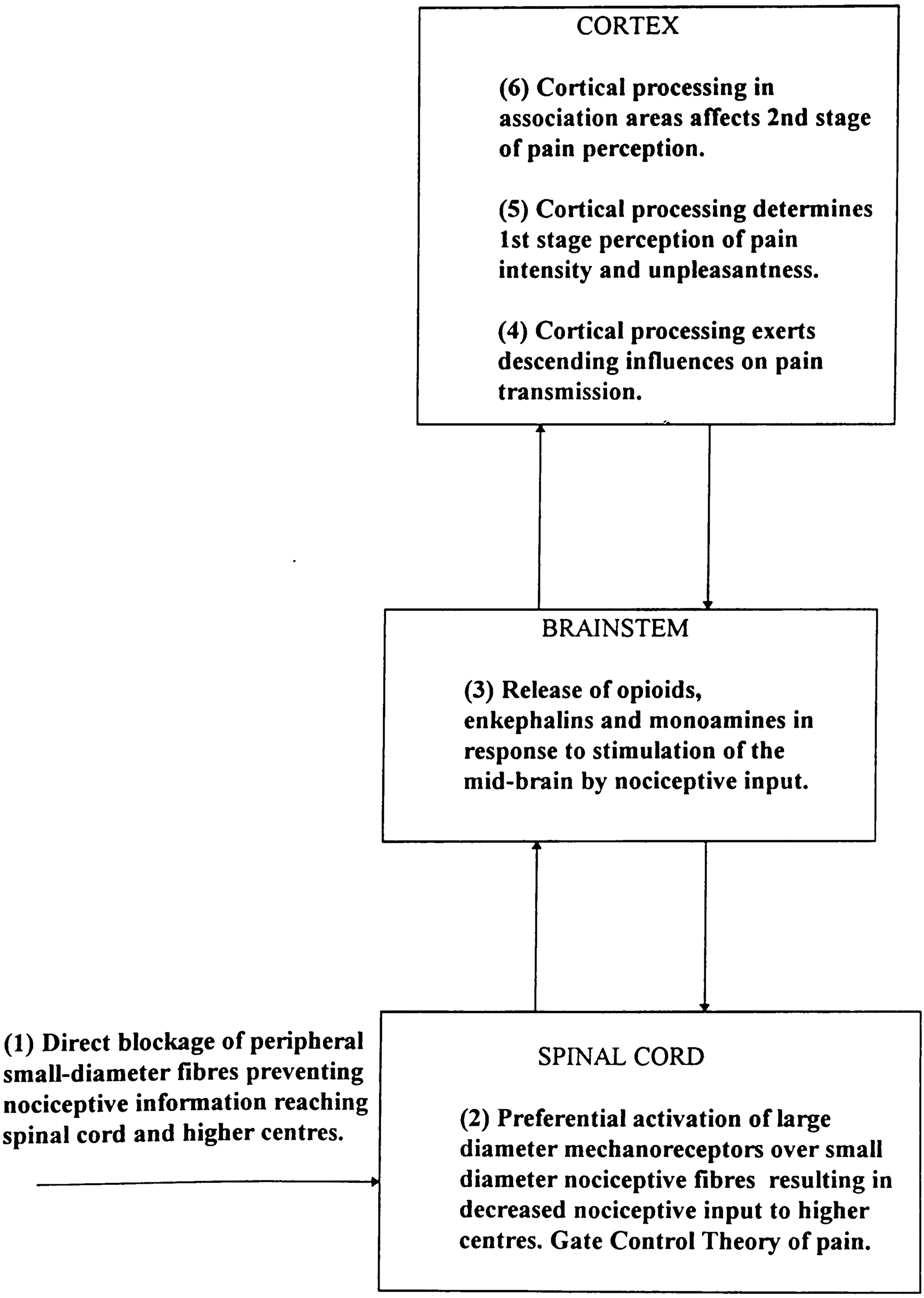
or low frequency / high intensity (acupuncture-like TENS). Both types of current can theoretically produce pain-relief by modulating nociceptive transmission of pain perception at a number of levels and all are initiated by the stimulation of peripheral afferent nerve fibres. A summary of proposed TENS mechanisms is shown in Figure 5.

4.2 : Peripheral mechanisms

It has been suggested that TENS modulates activity in afferent nerves as a result of blockage of small diameter fibres, specifically Aδ and / or C, in the peripheral nerves (Campbell and Taub, 1973; Ignelzi and Nyquist, 1976). The blocking effect of nociceptive afferent fibres has been proposed as occurring before the first synapse and is, therefore, thought to be entirely a peripheral mechanism with no involvement of the central nervous system. Campbell and Taub (1973) carried out 2 experiments stimulating the digital nerve of healthy human volunteers. The authors reported that the results of their 2 experiments supported a peripheral blocking mechanism of Aδ fibres for pain-relief by electrical stimulation but stressed that the current had to be continuous and of both high frequency and high intensity. The findings of Ignelzi and Nyquist (1976) supported the concept of Aδ fibre peripheral blocking when they carried out an investigation of nerve compound action potentials in the sural or superficial radial nerves of 10 anaesthetised cats.

Direct contradiction to the proposal of peripheral nociceptive fibre blocking by electrical stimulation was offered in a paper published by Swett and Law (1983) in

Figure 5 : Proposed mechanisms for TENS.



a study using chronic pain patients. Swett and Law (1983) compared their findings with those of Campbell and Taub (1973) and stated that the absence of painful sensations associated with the onset of high intensity electrical stimulation contradicted the conditions supposedly required for nerve block conduction. The authors did not rule out that some unspecified peripheral mechanism may interfere with action potential initiation in nociceptive fibres but stated that it was extremely unlikely to occur using the stimulus intensities selected by the majority of patients for pain-relief. The application of transcutaneous electrical stimulation employed by Campbell and Taub (1973) was equated by Swett and Law (1983) to rate in excess of 6-12 x sensory threshold intensity, as rated by their own scale and was therefore considered to be outwith the range commonly used in clinical practice. The findings of the paper by Swett and Law (1983), assuming similarity in action between the peripheral nerves of cats and humans, supported the theory that pain-relief by electrical stimulation is due primarily to large fibre stimulation and is produced by a central mechanism. This viewpoint was shared by Garrison and Foreman (1994) who reviewed the literature regarding peripheral mechanisms of pain-relief by electrical stimulation and summarised that the peripheral model was not in accordance with clinical experience and that pain-relief was most likely to be due to central nervous system involvement.

4.3 : Spinal mechanisms

Afferent nerves contain varying properties of different axon types and the fibres which relay noxious information (Aδ and C) possess different physical characteristics from the non-noxious afferent fibres carrying information from the cutaneous mechanoreceptors (Aβ). The relatively larger diameter and myelination possessed by the Aβ afferent fibres have the resultant effect of these fibres having a lower threshold to electrical stimulation than the fibres relaying noxious information (Guyton, 1991; Howson, 1978). The Gate Control Theory of Pain, originally devised by Melzack and Wall in 1965, suggested a theoretical framework for the use of electrical stimulation of afferent fibres for pain-relief. The specific neurophysiological and pharmacological mechanisms involved are being continually revised and updated (Handwerker, Iggo and Zimmermann, 1975; Steedman and Malony, 1987) but the main concept of the theory remains that selective activation of large diameter afferents such as the Aβ group causes segmental modulation within the spinal cord at the level of stimulation by decreasing the amount of nociceptive transmission through the spinal cord.

Research has clearly demonstrated that there is interaction between inputs in small and large afferent fibres within the dorsal horn and has associated this interaction with decrease in ascending noxious information projected onwards from the spinal cord and subsequent decrease in pain perception (Garrison and Foreman, 1994; Handwerker et al, 1975). The primary nociceptive areas of termination of Aδ and C fibres within the dorsal horn are the two most superficial layers (laminae I and II), with only a few fibres terminating in deeper laminae (Watson, 1982). While it

was initially proposed by Melzack and Wall (1965) that this was the result of presynaptic inhibition of the afferent fibres, more recent intracellular research gives support for a postsynaptic action on interneurones within lamina II (Handwerker et al, 1975; Steedman and Malony, 1987).

4.4 : Spinal mechanisms and relevant TENS parameters

Spinal segmental pain mechanisms are thought to be activated by TENS when large diameter Aβ afferent fibres are stimulated (Garrison and Foreman, 1994; Levin and Hui-Chan, 1993). Melzack and Wall's Gate Control Theory of Pain (1965) recognised the involvement of these fibre groups in their pain model and is supported by physiological evidence. It has been well established that if a mixed bundle of nerve fibres is stimulated by an electrical current the lower intensities will activate those fibres with the larger diameters due to their lower thresholds (Guyton, 1991; Woolf and Thompson, 1994). The relatively quick conduction velocity of Aβ fibres compared with those of the small diameter nociceptive afferents also means that non-noxious information from mechanical stimuli from the periphery reaches the spinal cord before impulses relaying noxious input.

With regards to parameter selection in order to selectively activate large diameter Aβ fibres, Woolf and King (1987, in Woolf and Thompson, 1994) reported that a stimulation frequency of greater than 25 Hertz must be reached. At higher frequencies (>25Hz) the combination of the nerve potential duration and latency periods of both the small and large diameter afferents results in sufficient hyperpolarisation of C fibres to reduce ascending information (see Section 2.4).

The use of high frequency currents in reducing noxious activation (blocking conduction) of evoked dorsal horn cells during TENS is supported by Garrison and Foreman (1994). The authors, in their study using anaesthetised cats, selected both a low frequency (5-45 Hz) / high intensity (50-60 mA) and a high frequency (50-125 Hz) / low intensity (5-40 mA) TENS current. Extracellular recordings were taken from 83 dorsal horn cells that normally respond preferentially to noxious stimuli. It was found that cell activity was more frequently decreased when the high frequency / low intensity TENS current was applied (1 way ANOVA; $p<0.001$).

Levin and Hui-Chan (1993) compared stimulus intensities of conventional TENS (frequency 100 Hz / intensity 3 x sensory threshold) with two forms of acupuncture-like TENS (frequency 0.1 Hz / intensity > 3 x sensory threshold and frequency 100 Hertz bursts at 4 Hertz / intensity > 3 x sensory threshold). The authors stimulated the median nerve of 17 healthy human subjects (age range 19-30; no other details given), allowing a rest period of between 30 to 60 minutes between testing sessions. In the case of the acupuncture-like TENS the current intensity was increased until pain tolerance level was reached. The authors did not give details in the paper as to how long the electrical stimulation was applied. The results of the study found that the intensities used with the acupuncture-like TENS ranged from 3 - 7.1 x sensory threshold (mean ± S.D. 4.58 ± 0.93 x sensory threshold). It was concluded in the paper (Levin and Hui-Chan, 1993) that because small diameter nociceptive afferents usually require 6 - 7 times sensory threshold stimulation values to be stimulated, and that this intensity of

current cannot be tolerated by many people, that in almost all clinical situations TENS will be activating large diameter A fibres. This conclusion is in accordance with that by Swett and Law (1983) but raises an important issue regarding the difference between using animal and human subjects. Variations in nerve activity between animal species, as well as recording discrepancies between percutaneous and transcutaneous techniques, makes it extremely difficult to directly compare nerve conduction studies but the results do suggest that current intensities of less than 6-7 x sensory threshold only stimulate Aβ fibres.

4.5 : Brainstem mechanisms

The Gate Theory of Pain (Melzack and Wall, 1965), although primarily proposing a spinal segmental model of pain modulation, also included a descending system which modulated spinal nociceptive transmission. The original theory proposed that input to this system was provided by ascending non-noxious information but more recent research supports the view that descending pain modulatory pathways which originate in the brainstem can be recruited by ascending noxious information and are, therefore, involved as part of a negative feedback loop (Basbaum and Fields, 1978; Belanger, 1985).

The two main brainstem areas which appear to be involved in the descending modulatory mechanisms are the periaquaductal grey matter (PAG) and the raphe nuclei, in particular the nucleus raphe magnus (NRM) (Thompson, 1988; Watson, 1982). It has been suggested that the PAG acts, via projections to the raphe nuclei, through the dorsolateral fasiculus (DLF) descending pathway to terminate

in the dorsal horn (Basbaum and Fields, 1978). The descending inhibitory mechanisms are thought to act at more than one level of the spinal cord and are therefore referred to as extrasegmental or diffuse noxious inhibitory control (DNIC) systems (Le Bars, Dickenson and Besson, 1979). There has been much research carried out investigating the exact chemical nature of the descending pain systems, with both opioid (e.g. enkephalins and beta-endorphins), and non-opioid (e.g. serotonin) substances being implicated (Belanger, 1986; Walsh, 1991; Wright, 1995).

4.6 : Brainstem mechanisms and relevant TENS parameters

It has been suggested that analgesia as a result of descending pain modulatory systems may partly be modulated through opioid pathways (Belanger, 1986; Walsh, 1991; Wright, 1995). Studies have been carried out using an opioid blocker (naloxone) to establish, indirectly, opioid involvement during TENS stimulation. Sjolund and Eriksson (1979) used 20 patients (no details given) diagnosed as having chronic pain and applied conventional TENS (frequency 50-100 Hz / intensity 2-3 x sensory threshold) to 10 patients and acupuncture-like TENS (frequency 100 Hz in 2 Hz bursts / intensity 3-5 x sensory threshold) to the other half of the sample. In each case electrodes were placed over the appropriate dermatome to treat the pain and all subjects had been using a portable TENS unit for at least 3 months (10-30 minutes, 1-4 times a day) prior to the study. Naloxone hydrochloride (0.8-1.6 mg) was administered to each subject while receiving TENS and injections (active or placebo) were repeated 4 to 8 times at 30 minute intervals. The conditions were double-blinded and sterile saline was

used as a placebo. Subjects were asked to rate their relief in pain intensity on a VAS 10 minutes after each injection. The results found that 6 of the 10 patients using the acupuncture-like TENS reported a decrease in stimulation-produced analgesia when naloxone was administered. No such decrease was reported by any of the 10 patients receiving treatment from the conventional TENS. The authors concluded that opioid mechanisms were activated only by low frequency / high intensity acupuncture-like TENS. The results of this study should be viewed with caution, however, as the pain assessment technique employed was quite crude (based on percentage change of VAS scores) and no statistical analysis of the results was undertaken.

Thompson (1988) summarised the results of 9 TENS studies which have used naloxone and reported that, in 4 of the 7 human studies and in both the animal studies, naloxone caused either a partial or total block of stimulation-produced analgesia. In general, naloxone was only able to affect analgesia produced by low frequency / high intensity acupuncture-like TENS, therefore supporting the findings of Sjolund and Eriksson (1979). Thompson stated, however, that it was not always possible to draw firm conclusions from the results, such as the study carried out by Freeman et al (1983, in Thompson, 1988) who was reported to have found that naloxone had no affect on stimulation-produced analgesia. These authors allowed their 9 subjects to select their own TENS parameters and used currents ranging from 10-100 Hertz frequency and unknown intensity. For this reason it could not be determined which types of afferent fibres were being stimulated. Another methodological issue with naloxone studies is the doses that

are administered. Woolf and Thompson (1994) suggested that the doses may not always be sufficient to block all types of opioid receptor and proposed that naloxone is not always an accurate indicator of opioid involvement.

Hughes et al (1984) used a more direct method of assessing opioid involvement during TENS application and measured blood beta-endorphin levels in 36 healthy subjects (18 male, 18 female; mean age 25 years) following high frequency (101-108 Hz) / low intensity (26-44 mA) (n=9), and low frequency (4-7 Hz) / high intensity (45-65 mA) (n=12) TENS stimulation. No statistical difference in beta-endorphin levels was reported between the TENS groups (χ^2=3.68; d.f.=2, p>0.10) but both groups had an increase in beta-endorphin level compared with the control group (n=10) which had received no TENS stimulation. The authors proposed that both types of TENS induced analgesia by increasing opioid levels and suggested that, as well as current frequency and intensity, parameters such as pulse width and electrode placement should be considered in order to identify the underlying neural mechanisms.

4.7 : Cortical mechanisms

Pain is well recognised as a multi-dimensional experience and pain perception has been found to be influenced by a variety of cognitive processes such as anxiety, depression, past pain experiences and cultural attitudes (Clancey and McVicar, 1992; Watson, 1982). As mentioned in an earlier section (see Section 3.4), these affect not only the higher level processing which modifies the cognitive-evaluative component of pain but also the first stage processing. Further, they can give rise

to processing which act on both sensory-discriminative and motivational-affective (lateral and medial) transmission systems selectively and so sensory input can be modulated in the somatosensory and limbic areas even before it reaches the cortical areas. The role which cortical processing plays in perceived pain intensity and unpleasantness has important implications for pain perception during clinical TENS treatment programmes, suggesting that both the physical sensation of the TENS current and the entire patient-therapist interaction procedure can affect the patient's degree of pain-relief from the modality. Cortical influences play an important part in the efficacy of a pain-relieving treatment and, with particular reference to TENS, positive treatment effects have been attributed to placebo action (Conn, Marshall, Yadav, Daly and Jaffer, 1986; Marchand, Charest, Li, Chenard, Lavignolle and Laurencelle, 1993). Placebo, in the context of TENS, can be considered as encompassing everything except the current and will be discussed in greater detail in Chapter 5.

4.8 : Conclusions

(1) There is evidence to support multiple potential mechanisms of action of pain modulation during TENS application. These can occur at spinal, brainstem and cortical levels.

(2) The level of pain modulation is thought to be dependent on a number of factors including TENS parameters, patient mood state and the patient-therapist interaction.

CHAPTER 5 : PSYCHOLOGY AND TENS

5.1 : Introduction

When testing the efficacy of a pain-relieving modality it is beneficial for the clinician or experimenter to know, if pain-relief is achieved, what mechanisms brought about the outcome. This chapter aims to highlight the psychological component of the pain response and, with particular relevance to the present study, the influence of control. Turner, Deyo, Loeser, Von Korff and Fordyce (1994) proposed three general reasons for clinical improvement in a patient's condition: (1) The first was natural history, or regression to the mean, which is a return to the patient's more natural state and occurs naturally over a course of time. (2) The specific effects of the treatment were included in the second category of response mechanisms and were considered to be attributable to the characteristics of the intervention treatment (for example, ice reduces inflammation). (3) The third category listed by the authors was non-specific

effects of treatment. This term is often interchanged with the phrase 'placebo effects' and encompasses all factors other than those considered to be specific to the active treatment (Turner et al, 1994) and, with particular reference to TENS, could be considered as encompassing everything except the current.

5.2 : Placebo effects

The word 'placebo' stems back to the Greek translation of the Hebrew Bible where the phrase 'I shall please' became 'placebo' (Gielen, 1989). The definition given today for placebo in the New Shorter Oxford English Dictionary (1993) is;

> 'A pill, medicine, procedure, etc., prescribed more for the psychological benefit to the patient of being given a prescription than for any physiological effect'.

Gielen (1989) described the placebo effect as that which cannot be attributed to factors characteristic of a specific treatment but that which must be attributed to other incidental treatment factors. In the same paper the author carried out a non-critical analysis of the literature and suggested that the placebo effect, within the profession of physiotherapy, is a result of the quality of the patient-therapist relationship and the complexity of the treatment. It was suggested by Klaber Moffett and Richardson (1997) that the interaction between the therapist and patient has an important influence on pain reporting and proposed that this communication could affect treatment outcome by a number of models including patient education, increased patient compliance, increased patient self-efficacy and positive patient expectations. Turner et al (1994) proposed that therapist qualities such as friendliness, sympathy, interest and prestige were associated with positive

effects of placebo as well as active treatments. Efforts to identify patient characteristics which increase the placebo effect have been inconsistent across placebo administrations and Richardson (1994) suggested that if individual patient characteristics have any significance in determining the response to placebo then it is likely that they interact with other variables such as treatment type and the individual's mood state. With regards to the influence of the treatment type on placebo response, Petrie and Hazleman (1985, in Richardson, 1994) reported that the placebo effect with sham TENS was increased when a visual display was incorporated and a strong positive verbal suggestion about the effects of TENS was included in the treatment regime. The clinical significance of the results of this study were not discussed.

Johnson, Ashton and Thompson (1993) carried out a detailed study investigating the influence of a selection of pre-existing patient factors (psychosocial variables, EEG variables and plasma concentrations of opioid peptides) on the efficacy of TENS. Twenty-nine patients (16 female, 13 male; age range 30-75; mean age 52.2) with a range of chronic pain conditions were used in the study and tested once on an out-patient basis. A follow-up questionnaire was sent to all the subjects 4 months after their initial attendance at the clinic and recorded whether patients were still in possession of and using a TENS unit. All tests were based on patients using the TENS unit at the parameters most frequently selected by themselves and a positive correlation was reported between TENS responders (classified by VAS response to average pain-relief by TENS) and the incidence of increased cortical responsitivity (increased somatosensory and auditory evoked

potentials). The authors were unable to report any other relationships being the pre-existing factors being tested and the assessed efficacy of the modality. The authors proposed that the reported efficacy of TENS may have been due to differences in individuals' cortical responsitivity which determined the effects that all forms of sensory stimulation had on pain perception. With regards to the psychological measures taken during the study, these incorporated the Eysenck Personality Questionnaire and a Hospital, Anxiety and Depression scale. The results of the study, in terms of psychological variables and their effect on the reported efficacy of TENS, suggested that it is unlikely that any one psychological variable in isolation affects pain perception.

Myths which surround the placebo response are that there is a fixed fraction (approximately one third) of people who respond to placebo and that the placebo response makes up a fixed fraction (again, one third) of the maximum possible response to a treatment intervention (McQuay, Carroll and Moore, 1995; Wall, 1992). Wall (1992) attributed these ideas to the misreading of Beecher's work carried out in 1955. This paper reviewed 15 studies of patients with various acute pain conditions and reported that, on average, symptoms were 'satisfactorily relieved' by the placebo in 35% of the patients treated. The placebo response rate, however, varied from 15% to 58% and corresponded with wide-ranging placebo responses reviewed by Wall (1992) from near 0% to almost 100%. It is difficult to compare placebo response rates across studies which employ different techniques of pain measurement and this is particularly true when percentage changes in pain are reported. Pain scales which rate percentage changes (often 50%) in pain

favour lesser pain intensities as lower initial markings require a smaller decrease in pain to rate a 50% change (Richardson, 1994). Problems with placebo rate reporting also emerge when other outcome measures such as grip strength or range of motion are taken with the assumption that they are directly related to pain perception (Richardson, 1994). The general consensus of placebo review papers (McQuay et al, 1995; Richardson, 1994; Turner et al, 1994; Wall, 1992) is that the placebo response is not consistent between studies and, more importantly, is not even consistent in individuals on different occasions. As mentioned earlier, the placebo response varies across treatment administrations and is due to countless factors of the patient-therapist interaction and the treatment being used.

5.3 : Proposed mechanisms for placebo effects

The exact physiological mechanism of action which placebo pain-relief employs was investigated by Levine, Gordon and Fields (1978) who conducted a study using 51 patients (27 male, 24 female; age range late teens to early thirties - no exact figures given) with dental post-operative pain. All patients were given the same dose of analgesia during surgery and afterwards were randomly assigned to one of three groups. One group was given naloxone, an opioid antagonist, two hours after surgery and a placebo one hour after that (n=11). The other groups were either given the two treatments in the opposite order (n=23) or were given placebo for both treatments (n=17) (5 subjects dropped out of the study). The authors asked subjects to rate their pain intensity on a 10cm long visual analogue scale 5 minutes before and 1 hour after receiving each treatment, as well as requesting a verbal response from each subject as to whether their pain had

decreased, increased or remained the same since the previous pain assessment. All subjects who received placebo first, followed by naloxone (n=23), were then categorised as placebo responders or non-responders based on their pain rating after the naloxone had been administered. Those subjects who reported that their pain had remained the same or decreased from 5 minutes before naloxone administration to the pain assessment 1 hour afterwards were defined as placebo responders (n=9) while those with increased pain during the same period were defined as placebo non-responders (n=14). The results indicated that subjects who were classified as placebo responders had a significant increase in pain reporting when administered naloxone (t-test; $p<0.05$ - no more statistical details given) and the authors concluded that placebo analgesia was involved with the release of opioid substances. It is difficult to accept the results of this study as the criteria used for defining placebo responders and non-responders was extremely crude and did not take into account the baseline pain intensity scores for each individual subject. It cannot be determined if the naloxone was solely responsible for changes in pain reporting and instead subjects who reported an increase in pain over the required time span may have been experiencing the wear-off of the surgical analgesia.

A number of placebo mechanisms of a psychological nature have also been suggested including expectancy effects, decreased anxiety, conditioning (learning) process and cognitive dissonance (Turner et al, 1994; Richardson, 1994). Expectancy effects suggest that a patient's expectation of treatment may help them become more positive about their condition and result in them gaining more

control of the situation and decrease their anxiety levels (Turner et al, 1994). The conditioning theory is based on research on learning and suggests that positive past experiences regarding a treatment will encourage a person to adopt a more positive approach to the present treatment programme. This will then tie in with the expectancy and anxiety effects but obviously negative past experiences can operate in the exactly opposite manner. Finally, the cognitive dissonance approach to placebo mechanisms is concerned with the holding of two or more beliefs which are psychologically inconsistent (Richardson, 1994). An example of this would be a patient prepared to undergo a treatment they found unpleasant in the belief that it will help relieve their symptoms. It is thought that the more unpleasant the patient finds the treatment the greater the placebo effect will be as to undergo that amount of suffering it must be doing them some good (Richardson, 1994).

It is difficult to completely separate any of these psychological processes as they more than likely interact with each other and also with physiological mechanisms such as that proposed by Levine et al (1978). Steps by clinicians and experimenters to increase the placebo response should, therefore, include physical and verbal cues that enhance any of the suggested psychological mechanisms.

5.4 : Placebo effects and TENS

The determination of either the specific, or the non-specific (placebo), effects of TENS is extremely difficult and is greatly dependent on the experimental design of the study and the criteria used as outcome measures of success. A wide range

of TENS studies have been carried out since the publication of the gate control theory of pain in 1965 by Melzack and Wall (see Chapter 4 for more detail). These TENS papers include animal and human experimental studies as well as those undertaken specifically in the clinical setting. In order to highlight the identification of placebo effects during TENS administrations three different types of study have been reviewed: (1) a human experimental pain study, (2) an acute clinical pain study and (3) a chronic clinical pain study.

Walsh, Liggett, Baxter and Allen (1995) used an ischaemic model of experimental pain to investigate the pain-relieving effects of TENS. Thirty-two healthy female volunteers took part in the study and were tested twice, with 48 hours between the two tests. Each subject was exposed to 10 minutes of the sub-maximal tourniquet test (see Section 6.4.6 for more detail) in the initial session and was then randomly assigned to one of four groups for the second test: (1) control group (no TENS) (n=8), (2) placebo group (no battery TENS) (n=8), (3) high frequency group (110Hz TENS) (n=8) or (4) low frequency group (4Hz TENS) (n=8). The control group underwent the same pain induction procedure as before while the other three groups had one electrode attached to Erb's point and the other lateral to C6/7 during the ischaemic pain test. All the TENS subjects were instructed to adjust the current intensity to control their pain but the placebo group were told before testing that they may or may not feel any sensation under the electrodes. The whole testing procedure was double-blinded but it is obviously very difficult to effectively blind subjects to a treatment such as TENS which has a definite physical sensation. The subjects rated their pain intensity on a

computerised 10cm long VAS at one minute intervals during both pain induction sessions and the results of the study (one-factor ANOVA) showed a statistically significant differences between groups ($p \leq 0.02$) for pain scores. Post-hoc Fisher tests indicated that there was no statistically significant difference between the low frequency TENS group and the subjects receiving placebo TENS although the same statistical test showed that the low frequency TENS group produced statistically significantly lower pain scores than both the high frequency TENS group and the group receiving no TENS (control group) (no statistical details given).

An acute clinical pain study was carried out by Conn et al in 1986 investigating the effects of TENS following appendicectomy. Consecutive patients (n=42, no other details) undergoing an emergency form of the operation were randomly assigned to either a control group, sham TENS group or active TENS group. The two groups receiving TENS had an electrode placed either side of their wound and kept in situ for 48 hours. The authors gave no information as to the parameters of TENS employed in the active group and the methodology indicated that the clinicians were not blind to the group allocation. The patients were asked to rate their pain intensity post-operatively on a VAS and analgesia requirements were monitored over the 2 consecutive 24 hour periods of TENS placement.

Analysis of the data found that, although both TENS treatments were significantly more effective in reducing pain (both outcome measures) ($p<0.01$) than the control group, there was no statistically significant difference between the sham

TENS and the active TENS groups. The authors concluded that TENS was not a suitable pain-relieving modality following surgery due to it being no better than placebo. This standpoint seems rather negative as pain-relief, regardless of the mechanisms by which it is induced, must surely be viewed as a clinical success. Greater detail of the parameters of the active TENS employed in the study may have revealed more answers as to the similarity in outcomes between the two TENS groups.

Marchand et al (1993) undertook a clinical chronic pain study using TENS. Forty-two patients (18-60 years) who had experienced low back pain for more than six months were recruited to participate in the study by medical referral and newspaper advertisements. The patients were randomly assigned to either a TENS group (frequency 100Hz; pulse duration 125μs; intensity 'clear but non-painful paraesthesia'), placebo-TENS group (no current) or control group. The group matching was done by controlling for sex, weight, diagnosis and pain severity so that the three groups possessed similar patient characteristics as their baseline measure. Placement of electrodes in the two TENS groups involved positioning in the appropriate dermatome level and these positions were replicated for each 30 minute treatment session. Patients attended sessions on an out-patient basis twice a week for 10 weeks. Interestingly, the placebo TENS apparatus was fitted with a visual and sound feedback system which, as suggested by Petrie and Hazleman (1985, in Richardson, 1994), may increase the placebo response. An independent experimenter adjusted the current intensity for all the TENS patients until a sensation was reported. All the patients in the placebo group reported a sensation.

Patients in the control group received no treatment but were informed they would receive some six months later and were involved in the pain assessment procedure. The authors adopted a multi-dimensional approach to pain assessment and evaluated both pain intensity and pain unpleasantness on separate 10cm long VASs (see Section 7.2.1 for more detail). Patients were asked to rate their pain every 2 hours over 3 days following each treatment session. This procedure was then replicated 1 week, 3 months and 6 months after the 10 week treatment programme had been completed.

Analysis of the pain scores using an ANOVA showed that immediately following treatment the reduction in pain intensity was significantly greater for TENS than placebo TENS ($F=4.22$; d.f.=1,24; $p=0.05$) but this was not the case for the pain unpleasantness scores ($F=1.38$; d.f.=1,24; $p=0.252$). Post-hoc Dunnett t-tests were then employed to investigate the long-term effects of TENS and at 1 week after treatment, once more, TENS was significantly more effective than placebo TENS in reducing pain intensity ($t=2.50$; d.f.=3,72; $p<0.05$) but not pain unpleasantness (no statistics given). No difference was found between the two groups (intensity and unpleasantness) at either the 3 month or 6 month pain assessment stages after the end of treatment. The results indicated the selective nature of the placebo response on the affective component of the pain response and also showed the long-term effects that both TENS and placebo TENS can have on chronic pain-relief.

5.5 : Control

The issue of placebo effects within the field of pain management has been addressed and it has been identified that components of the treatment procedure, such as patient-therapist interaction and patient mood state, can alter the patient's pain perception (Gielen, 1989; Klaber Moffett and Richardson, 1997; Richardson, 1994; Turner et al, 1994). An aspect of pain management procedure which has been investigated with regards to having an effect on pain perception is control. The concept of control has no formal definition but Thompson (1981) provided a general statement of ;

> "Control can be defined as the belief that one has at one's disposal a response that can affect the aversiveness of an event."

Importantly, Thompson's definition recognises that control does not have to be exercised, or even be real, to be effective. It is impotant to note, however, that within the context of the present study control is meant as being the ability of either the subject or experimenter to adjust the current intensity dial on the TENS machine.

A number of studies which have investigated the influence of control on pain outcome measures are reviewed within this section. The majority of the studies refer to aversive electric shock application as the method of pain induction and are therefore not directly applicable to the present study but due to the lack of

literature which has looked at the relationship between pain and control it has been necessary to include the reviewed material.

The relationship between perceived self-control of pain and pain reporting was investigated by Toomey et al (1991). Fifty-one subjects (34 females, 17 males; mean age 42 years +/- 13 years) were employed in the study, all of whom were patients attending an out-patient pain clinic with non-malignant myofacial pain. Subjects were requested to complete the Pain Locus of Control Scale (PLOC) to assess their perceived personal control of pain, as well as mark their average, worst and least pain intensity over the previous week on a 10cm long visual analogue scale. During the pain assessment procedure subjects were also asked to report about their pain frequency and the functional interference they experienced due to their pain. The authors did not state at which stage of the treatment programme any of the patients were at when taking part in the study.

A total of 48 subjects completed the PLOC and these scores were divided into two groups, high scores (n=24) and low scores (n=24). The split in scores was achieved by dividing the scores at the median value. Both groups were compared on each of the dependent variables in the study and correlational analyses were carried out to establish the relative strengths of the relationships (Pearson or Spearman Correlation test, as appropriate). The results showed that patients reporting greater control of pain (high PLOC scores) rated their average pain level ($p \leq 0.001$) and least pain level ($p \leq 0.02$) as significantly lower than patients reporting less personal control of pain (low PLOC scores). In addition, high

PLOC score patients rated significantly higher periods of time without pain ($p \leq 0.004$) than the low PLOC score group. No statistically significant differences were reported between the two groups for functional interference due to their pain although the authors recognised that this may have been attributed to the assessment structure as well as the degree of patient willingness to report variations in pain-related behaviours during initial phases of treatment.

Weisenberg, Wolf, Mittwoch, Mikulincer and Aviram (1985) conducted a laboratory study in which 50 healthy male subjects (mean age 24.3 years; age range 18-33 years) received electric shocks to their left wrist. All subjects were given the same number of shocks but 5 independent groups were used (n=10) for variations of perceived control. The variation in conditions was determined by the experimenter or the subject having control of attaching the electrodes and/or the decision to remove one of the electric shocks. The study also investigated the effect of predictability on pain response. Each group undertook two tests (each containing three trials), once warning the subjects in advance when the shock would arrive and once without a warning. The order of the testing was randomised and a 5 minute rest was permitted between the two tests to allow recovery from shock adaptation. The experimenters assessed pain intensity after each electric shock using a VAS. Statistical analysis was carried out using an ANOVA and the results showed significant main effects in the relationships between VAS pain intensity scores and trials ($F=4.80$; d.f.=2,80; $p<0.01$) as well as for the interaction of conditions x trials ($F=1.98$; d.f.=2,80; $p<0.06$). Tests carried out to look for simple main effects showed that in all 3 trials subjects who

had control over both electrode attachment and shock administration produced the lowest pain intensity VAS scores.

Before commencing the study, each subject completed a validated questionnaire to assess perceived self-efficacy. Self-efficacy is a measure of a person's perception of possessing coping abilities in aversive situations and has been thought to determine how much effort a person will give and how long they will tolerate noxious stimuli (Weisenberg, 1994). Evidence has even been produced to suggest that perceived self-efficacy can effect the body's endogenous opiate and immune systems thus altering the pain response (Wiedenfield, O'Leary, Bandura, Brown, Levine and Raska, 1990). Results linking VAS scores to self-efficacy showed that experimenter-control decreased the perceived pain intensity scores in those subjects with high self-efficacy but increased scores on the same measure in those with low self-efficacy. The authors (Weisenberg et al, 1985) concluded that giving control to a subject who was already anxious may have increased their pain response. They also suggested that control which was perceived as inadequate may have been more distressing to a subject than no control at all.

Kanfer and Seidner (1973) conducted a study to compare pain tolerance between three randomly assigned groups of healthy female subjects (n = 45), all of whom had their hands immersed in ice cold water. Group 1 (n=15) had complete control over the slide show they were watching during the procedure, being able to change the pictures as they wished. Group 2 (n=15) had their slide show controlled by the experimenter, and the remaining subjects (n=15) acted as a

control group (no slide show). For Groups 1 and 2 the slide show consisted of travel scenes that were irrelevant to the study. Subjects were also asked to complete a post-test questionnaire, asking them about their thoughts during the immersion and asking for a discomfort rating of the icy water (8 pt VRS) and their general sensitivity to pain. The results of the study, using an ANOVA, showed a significant groups effect on tolerance times ($F=15.89$; $d.f.=2$; $p<0.01$). A Multiple Scheffe follow-up test showed that the subject-controlling mechanism was significantly more effective in increasing water tolerance times than the experimenter-controlled mechanism. No significant difference, however, was found between groups for the 8 point verbal rating scale ($F=0.76$; $df=2,42$; $p>0.05$). The authors were unable to attribute the variations they found in pain perception to variations in water tolerance times but this may have been due to the lack of sensitivity of the pain scale employed. The VRS only possessed 8 response categories, meaning that a relatively large change in pain perception was probably required to register an alteration in pain reporting. The authors may have found quite different results if other descriptors had been used or more response categories had been offered to the subjects.

Staub, Turskey and Schwartz (1971) carried out two experiments with 20 different male college students participating in each (no further details given). During both experiments subjects were seated in a sound-proof room, observed by an examiner through a one-way mirror and spoken to through a two-way intercom system. In experiment 1 and 2 the subjects were divided into two groups, a self-control group ($n=10$) and a no-control ($n=10$) group. All subjects

were informed that they would receive electric shocks to the left forearm (1second duration) and that the intensity would increase each time (2mA). Each subject was asked to report at four different levels of stimulation; (1) when they first felt the stimulus (sensation threshold), (2) when it became uncomfortable, (3) when it became painful (pain threshold) and (4) when they did not wish to go any higher (pain tolerance). The self-control subjects were given a switch which enabled them to administer the electric shocks themselves once a light was turned on. Neither the switch or the light was available to the no-control group where the examiner administered the electric shocks. Experiment 2 followed a similar procedure to experiment 1 except subjects in the self-control group were given a second switch which allowed them to control the increase in intensity of the electric current (1, 2 or 3 increments - each 2mA). As in experiment 1, the self-control group received a light to inform them of when they could administer the next electric shock. Unlike the first experiment, however, the time that this light remained lit varied from 10 to 20 seconds so as to decrease predictability for the no-control subjects.

Differences between the self-control and no-control groups for both experiments were evaluated using matched t-tests. In experiment 1 no significant differences in mean shock intensity was noted at any of the four levels of judgement. Differences, however, were noted in experiment 2 when self-control subjects were given the choice of altering the current intensity. Subjects in the self-control group reached significantly greater levels of current before they reported it as uncomfortable than subjects in the no-control group ($t=2.44$; $d.f.=9$; $p<0.02$).

Also, subjects in the self-control group tolerated significantly higher intensities of electric shock ($t=1.82$; $d.f.=9$; $p<0.06$) when they were allowed to administer them themselves as opposed to the experimenter controlling the current.

Thompson (1981) suggested that decreased pain perception as a result of giving a person control over an aversive situation may be due to a reduction in anxiety by the person in pain. This viewpoint supported that reported by Pervin (1963) who carried out a study using 30 male undergraduate students. The apparatus consisted of three lights which acted as signals for an electric shock to the subject's calf and two levers which did (control switch), or did not (no control switch), produce the electric shock. The study took the form of a 3x2 experimental design involving six conditions. The 2 components of the study were the certainty dimension (signal, no signal, inconsistent signal) and control dimension (control, no control). In the 6 conditions the subjects could (a) either control the application of the electric shock or have it administered by the experimenter and (b) they could predict when the shock would occur or could not. A trial consisted of a 5 second duration light signal followed by a lever being thrown (shock or no shock) and a 5 second rest. Each of the 6 conditions was made up of 12 trials and a paired comparison technique was used to investigate the relationship between the conditions. Each subject was tested over three 1 hour sessions spread over one week and a total of 450 paired comparisons were made (150 on each day). At the end of each paired comparison subjects rated both their pain intensity and anxiety on a 11 point verbal rating scale. Data analysis involved comparing the mean pain scores for each condition with the mean of the other

conditions combined. The authors reported no statistically significant interaction effects between the control and no control groups, although it was stated that the mean anxiety ratings of the former were lower than those for the latter (no statistics given).

The results of laboratory studies are therefore inconclusive, although it appears that control can have an effect on pain behaviour without necessarily producing a significant change in perceived pain reporting. The non-significant results found in certain studies may be due to the insensitivity of the scale being used, in some cases a verbal rating scale (VRS) (Kanfer and Seidner, 1973; Staub et al, 1971). It could be necessary that more response categories are given to the subjects before a change in pain perception can be recorded, such as with a visual analogue scale (VAS) (see Chapter 7 for greater detail on pain assessment).

Control raises other issues regarding pain assessment, including the timing of application. The review of pain neurophysiological mechanisms identified two distinct phases of pain perception and stressed the relative input of the three components of the pain response (sensory-discriminative, motivational-affective and cognitive-evaluative) during each of the two stages (see Section 3.4). The initial emotional response (motivational-affective) of a person in pain is thought to be influenced by the emotional context in which the stimulus is delivered, including attentional mechanisms (Lima, 1997). Anxiety is an emotional state which has been referred to (Weisenberg et al, 1985) and assessed (Pervin, 1963) during experimental studies investigating the influence of control on pain

perception. In turn, anxiety has been linked with attention during acute experimental pain induction (electric shock) (Janssen and Arntz, 1996) and it has been suggested by the authors that giving a person a diversion from the pain stimulus reduced their anxiety levels and pain perception. Giving a person control over an aversive situation could provide the subject with a diversion from the painful stimulus and instead allow them to focus their attention on their ability to control the pain (e.g. applying the stimulus themselves instead of the experimenter). It could be, therefore, that decreased pain perception under increased levels of subject control may, in part, be due to the subject's attention being diverted away from the painful stimulus. Miron, Duncan and Bushnell (1989) carried out an experiment investigating the effects of attention on the intensity and unpleasantness of experimental thermal pain. Healthy subjects (4 male, 3 female; age range 20-25) were seated in front of a computer screen and exposed to varying levels of thermal (contact thermode attached above the lip) and visual (light placed on top of the computer screen) stimuli. An initial testing session was incorporated into the study during which the subjects were introduced to the experimental procedure and pain assessment scales. The pain scales consisted of two lists of words, one containing intensity descriptors and the other containing unpleasantness descriptors. Subjects were asked to rate each descriptor on a perceived line length using a VAS (cross-modality matching). In this way each descriptor was assigned a numerical value for the purposes of data analysis. The experimental procedure involved the subjects being exposed to 80 trials during which either the thermal or visual stimulus increased. Subjects were correctly or incorrectly informed (random ordering) as to which stimulus would

increase before each trial started (message on computer screen). The appropriate stimulus was increased during each trial until the subject detected the change (registered by the subject pressing the computer 'return' key). After each trial subjects were asked to rate both the intensity and unpleasantness of the thermal stimulus by choosing a word on each of the descriptor scales. The results of the experiment, using a repeated measures ANOVA, showed that subjects rated both mean pain intensity and unpleasantness of the thermal stimulus higher on correctly signalled than incorrectly signalled trials (intensity F=13.54; d.f.=2,5; p=0.010: unpleasantness F=11.736; d.f.=2,5; p=0.013). The authors stated that the modulation of both components of the pain response by direction of attention suggested that changes in the subjects' perceived unpleasantness of the stimulus were at least partially a consequence of alteration of the perceived intensity of the stimulus. The finding that intensity and unpleasantness components of pain are altered to a similar degree by changes in attention is consistent with an interpretation that these effects are occurring at an early stage in sensory processing. This viewpoint is substantiated by neurophysiological research which was reported to have investigated monkeys trained to perform tasks while their attention was focused towards either visual or noxious thermal stimuli (Bushnell, Duncan, Dubner and He, 1984, in Miron et al, 1989). The results were reported to have shown an increased receptiveness of nociceptive neurones in the dorsal horn when the monkeys were attending to the noxious thermal stimulus than when attending to the visual stimulus. Giving a subject control of a pain-relieving modality such as TENS provides a distraction from a painful stimulus and neurophysiological research has provided evidence to support the view that

control can influence both 1st and 2nd stage pain perception (Guilbaud et al, 1994; Lima, 1997). The effect of control, however, would be expected to have a greater influence on 2nd stage pain perception as higher levels of cortical processing in the association areas would allow for detailed evaluation of the treatment process. These research findings underline the importance of differentiating between the types of pain being treated (chronic, acute, experimental) when investigating the pain-relieving efficacy of TENS.

An important point to note is that, with regards to the studies involving control, no literature has been published investigating the effect of perceived control on pain perception using TENS. TENS, due to its portability, is a pain-relieving modality which can be applied by patients themselves in their own home and so allow patients to take increased control of their pain management (Ellis, 1995). Indeed, it has been suggested by Toomey et al (1991) that TENS is a suitable modality with which to investigate the relationship between pain perception and the increased perception of personal ability to control pain.

5.6 : Conclusions

(1) The literature has identified that factors not specific to a pain-relieving modality can influence treatment outcomes and that these factors can be referred to as placebo effects.

(2) With reference to TENS, placebo effects can be considered as encompassing everything except the current and have been found to play a part in the outcome of TENS studies.

(3) Control has been identified as a variable affecting pain perception and, based on neurophysiological principles, can influence pain assessment outcomes during both the 1st and 2nd phases of pain perception.

(4) Research has yet to be published investigating the effect of increased subject control on pain perception using TENS but it has been suggested (Toomey et al, 1991) that the modality is suitable for investigating such a relationship.

CHAPTER 6 : THE EFFICACY OF TENS IN RELIEVING PAIN

6.1 : Introduction

Gracely (1994) identified 3 types of pain study: (1) those which use patients within a clinical environment, (2) research using laboratory animals, and (3) laboratory-based investigations using healthy human subjects. Each form of study has its limitations, with animal experiments encountering problems such as interspecies differences and the inability of animals to give a subjective response to painful stimuli. It is the pain assessment issue that poses the greatest difficulty in determining the pain-relieving efficacy of TENS and for that reason only human studies will be considered in this chapter. For the purposes of the present study it is important to establish the research basis for the pain-relieving efficacy of TENS in both the clinical and experimental setting. Differences between clinical and experimental human pain studies will be discussed later in the chapter (Section 6.3), including the shortcomings unique to both types of study.

6.2 TENS and clinical pain

As already mentioned in the previous chapter about placebo effects (Section 5.4), clinical pain studies can be divided into two major categories of acute (short-lasting) and chronic (long-lasting) pain. A large number of papers have been published in peer-reviewed journals within the past 15 years reporting the efficacy of TENS in a wide range of conditions but, as mentioned in Chapter 1, a lack of studies carried out with a rigorous study design has led to often contradictory study outcomes. The gold standard in clinical studies has been identified as being the randomised controlled trial (RCT) (Ernst and Resch, 1996) and so, within this section, a number of review papers will be included which report the outcomes of only those studies categorised as having the criteria to be RCTs. It is not the purpose of this section to report all the many conditions which have been treated with TENS but instead to review a sample of those acute and chronic clinical pain studies which have tested the pain-relieving efficacy of TENS. In the case of reviewed studies which have been carried out in a non-randomised or uncontrolled manner, methodological flaws are highlighted and the validity of the outcomes questioned with respect to the study design.

Post-operative pain is a major use of TENS in acute clinical care and one such study was carried out by Cuschieri, Morran and McArdle in 1985. One hundred and six patients were included in the study, all of whom were patients undergoing elective abdominal surgery in a single hospital unit. Exclusions from the study included patients with a psychiatric history and those receiving narcotics prior to surgery. Immediately following surgery patients were randomly assigned to either

an active TENS group (frequency 80Hz, pulse duration 170μs, intensity 'tingling sensation without discomfort') or a sham (no battery) TENS group where, in both groups, the 2 electrodes (size not given) were placed one either side of the incision. The authors assessed the qualitative differences between the two patient groups using a Chi square test and reported that the groups were comparable in terms of age, sex and weight. It was also reported that there was no difference between the groups with regards to number of smokers or upper abdominal incisions (no statistics provided).

All the patients involved in the study were introduced to the TENS device prior to surgery and a short demonstration was carried out to establish the amount of current required to produce a 'tingling sensation without discomfort'. The required intensity was recorded and set by a clinician post-operatively. Conditions throughout the study were double-blinded. The authors reported that the TENS was checked twice daily but it was not stated whether the TENS intensity was maintained at the same level or adjusted to allow for accommodation. It should be considered that the use of a predetermined current intensity does not allow for changes in sensory perception which may have occurred following surgery i.e. a TENS current that gave a 'tingling sensation without discomfort' prior to surgery may have felt completely different once the surgery had been performed.

Pain assessment following surgery was carried out using VASs (no further details given) which were completed by all the patients prior to administration of the first daily injection of analgesic and afterwards twice daily for 3 days. Patients were

asked to record their average pain over the previous 12 hours and morphine requirements were also noted. The pain scores were compared using the Mann Whitney U-test and the results showed no significant difference between the severity of pain experienced in either the active or sham TENS groups (no statistics given). The morphine requirements were also similar between the groups with the sham TENS group receiving a mean amount of 50mg (range 10-190mg) while the active TENS group received a mean amount of 59mg (range 10-140mg).

The authors concluded that the results of the study did not support the use of TENS following abdominal surgery but this is difficult to accept with the absence of a true control group receiving no TENS. The results of the post-operative study carried out by Conn et al (1986) (see Section 5.4) found that, although there was no significant difference in pain-relieving efficacy between sham and active TENS, both were significantly more effective than the control group. The results of the Cuschieri et al (1985) study, therefore, support the presence of a placebo effect with TENS but cannot support the view that TENS (active or sham) is no better than receiving no TENS at all.

A systematic review of the use of TENS with post-operative pain was carried out by Carroll et al in 1996. The authors, searching in both Medline™ (1966-1995) and the Oxford Pain Relief Database (1950-1992), found 46 studies of which 17 were categorised as RCTs. Inclusion criteria for the initial search was that the study was investigating acute post-operative pain, was written in the format of a

full paper and had a subject number greater than ten. Each study was scored by five independent readers on a three-point scale; (1) randomisation carried out, (2) randomisation and design carried out correctly and (3) subject number greater than ten and reasons given for any withdrawals.

The results of the review paper (Carroll et al, 1996) found that of the 29 studies classed as RCTs, only 19 had pain outcomes. Of these 19 non-RCTs, 17 reported a positive outcome with TENS. This was in contrast with the 17 RCTs where only 2 studies reported a positive outcome. The authors concluded that non-randomisation of studies have the effect of over-estimating treatment effects and that this was evident from the TENS papers reviewed.

Another form of acute pain which is commonly cited in TENS studies is obstetric pain. Carroll et al (1997) compiled another systematic review of the effects of TENS with respect to labour pain and, using the same search strategy as used for the post-operative pain review (Medline™ and the Oxford Pain Relief Database), found eight studies which fulfilled the RCT criteria; (1) randomisation carried out, (2) randomisation and design carried out correctly e.g. blinding and (3) subject number greater than ten and reasons given for any withdrawals. Each of the eight studies were then read independently by five different researchers and given a score of between 1 and 5.

A total of 712 women were included in the review, with 352 women receiving active TENS and 360 acting as controls. As a control three studies used

conventional analgesic administration (no TENS) while the remaining five used sham TENS. Of the eight studies, three were classed as having a positive outcome and five a negative outcome. Interestingly, however, none of the studies recorded any difference in pain scores during labour between TENS and control. One of the three positive results in the search was based on the number of additional pain relieving required as its only outcome and the other two positive results were based on time both to and between local anaesthetic outcomes. The authors concluded that the evidence from randomised trials for pain-relieving benefits from TENS during labour was not compelling but stated that the modality should still be viewed as useful as it was apparently not harmful (compared to, for instance, epidural local anaesthetics) and may do some good.

The role of TENS in chronic pain, as in acute pain, covers a multitude of conditions. Robinson (1996) carried out a review of TENS studies investigating pain management in musculoskeletal disorders. The primary focus of the paper was the review of studies investigating non-specific low back pain but other areas discussed included arthritic conditions and soft tissue inflammatory disorders. The review was restricted to those studies which the author believed had held the greatest impact on clinical TENS use in patient populations. Robinson (1996) reviewed a number of studies in detail and then compiled a table listing methodological and documentation flaws within them. These included inadequate exclusion criteria, no control group, inappropriate statistical analysis and failure to describe the TENS stimulation parameters. The author was unable to either support or refute the efficacy of TENS for pain-relief in musculoskeletal disorders

and concluded that more well-designed, randomised, controlled prospective studies on TENS were required to answer questions about the modality.

A major study carried out on the use of TENS with low back pain, and one which was mentioned in the review paper by Robinson (1996), was published by Deyo, Walsh, Martin, Schoenfeld and Ramamurthy in 1990. Individuals for the study were recruited by newspaper advertisement which raises the question of normality within the subject population. The exclusion criteria for the study were clearly stated and once these applicants had been declined a total of 145 subjects were included in the study (age range 18-70). The subjects were randomly assigned to 1 of 4 groups; (1) active TENS (n=36), (2) active TENS and exercise (n=37), (3) sham TENS (n=36) or (4) sham TENS and exercise (n=36).

The subjects in the 2 groups receiving TENS were given written and oral instructions regarding its use and were instructed to use the modality at least 3 times a day for 45 minute periods during the 6 week study. The parameters of the TENS current were set at a frequency of 80-100Hz and intensity of 30mA (no other details given) for the first two weeks and then altered to a frequency of 2-4Hz and intensity of 100mA after the two week period had ended. The subjects were allowed, after the low frequency TENS trial, to select either of the two settings for the final two weeks of the study. In each case the 2 electrodes (no size stated) were placed at the site of pain but then moved as necessary to optimise pain-relief. The sham TENS units were used in exactly the same manner as the active TENS units except no current was supplied to the electrodes. Subjects

supplied with sham TENS were told that they might, or might not, perceive stimulation from the units. The groups receiving exercise as part of their treatment were given a series of 12 daily exercises (3 for relaxation; 9 for hip, spine and lower limb flexibility) of which they were instructed to carry out 2 or 3 repetitions, then repeat in the reverse order. Subjects in all 4 groups attended a clinic twice weekly during the first 4 weeks of the study during which time they received moist heat treatments (hot packs) and advice about their treatment. Heat packs were also lent for home use and subjects were advised to use them on painful areas for 10 minutes a day.

Assessment of the effects of the treatments was carried out at 2 and 4 weeks of the study programme and again 8 weeks after the treatments had ended. A multivariate analysis of variance investigated 9 outcome measures of function, pain and physiological outcome and found that, at the 4 week stage of treatment, there were no statistically significant differences in any outcome between the subjects receiving active TENS and those receiving sham TENS ($p>0.2$ in each case). The authors concluded that TENS was no better than placebo and added no apparent benefit to that of exercise alone.

The study by Deyo et al (1990) raises a number of issues, many of which were addressed in letters to the authors following its publication. The introduction of another modality to the study, in the form of heat packs, makes it difficult to establish if it was the TENS and / or exercise contributing to the results. It has also been noted that the outcome measures were biased towards physical activity

levels and therefore would have favoured the assessment of exercise rather than TENS. Most importantly, the optimal parameters for relief of chronic low back pain cannot be established in the study as not all the subjects followed the same parameter settings. The authors reported that only 23% of the subjects in both the active and sham TENS groups remained using the high frequency TENS current after the initial 2 week period and so it can only be concluded that the low frequency current was the preferred one. The results of this study contradict those of Marchand et al (1993) (reviewed in Section 5.4) who found active TENS to be more effective than sham TENS in reducing pain intensity 1 week after treatment. It remains unclear if the results obtained in the Marchand et al (1993) study were due to different stimulating parameters or more sensitive pain assessment tools (pain intensity and pain unpleasantness VASs).

An investigation as to how long-term users of TENS set their parameters was carried out by Johnson, Ashton and Thompson in 1991(a). One hundred and seventy-nine patients (female n=82, male n=97; age range 24-85, mean ± S.D.= 55.2 ± 12.9), randomly selected from hospital files and in possession of a TENS machine (lent from the hospital) for more than 3 months to treat a chronic pain condition, took part in the study. All patients participating in the study were classified according to the anatomical region of their pain, aetiology and diagnosis clusters and were then requested to complete a questionnaire specific to TENS and designed by the authors. Of the total number of patients in the study, 107 (female n=58, male n=49; age range 24-85) attended the hospital and had the electrical characteristics of their TENS machines tested at sensory threshold,

therapy and pain threshold levels. Patients who were free of pain at the time of the visit were asked to use 'normal therapy settings' and in all cases a mean of 3 repetitions was calculated. Four types of stimulators were used in the study and with those offering a burst facility the procedure was repeated in the burst mode.

With regards to the efficacy of TENS in relieving pain, subjects were asked to rate their degree of pain-relief obtained from their TENS machine on a VAS labelled 'no relief of pain' (assigned a value of 0) and 'total relief of pain' (assigned a value of 10). The results of the study showed that 47% (n=79) of patients reported that TENS reduced their pain by half or more and that only 13.7% (n=23) of patients stated that TENS produced no relief to their pain (score of between 0 and 1 on the VAS). A one-way analysis of variance (ANOVA) found that the VAS scores were not significantly different when classified in any 1 of the 3 categories of anatomical region of pain, aetiology of pain or diagnostic clusters. Regarding parameter preferences, 56% (n=72) reported using continuous TENS stimulation in preference to burst mode and 70% (n=61) used a current intensity less than 10mA above their sensory threshold. Over 75% (n=68) of patients in the study used frequencies in the range 1-70Hz but the authors stated that this finding may be due to the designs of the TENS machines. Interestingly, no correlation (Pearson correlation coefficient) was found between the selected current frequency and the degree of pain-relief achieved using TENS ($r=0.132$, $d.f.=89$, $p>0.05$). The authors commented on the lack of correlation between patient, stimulator and outcome variables and suggested that parameter

preference may be due to a combination of factor including those of a practical (type of stimulator), psychological (personality) and physiological (aetiology and type of pain) type.

A review of clinical TENS studies shows the wide spectrum in which the modality can be used. The portable and relatively inexpensive nature of the modality makes it easily accessible to many different patient groups. The use of TENS ranges from the passive application of the modality to the patient post-operatively to the more active and informed usage that occurs when patients are taught about the machines and instructed how to apply them themselves in their own homes. The large number of variables that occur in the clinical setting and the influence which these can have on pain perception (see Chapter 5) may contribute to the often contradictory findings in clinical TENS studies. The variation in current parameters (frequency, intensity, pulse duration, waveform), application (electrode placement, length of treatment) and context (hospital /clinic or patients own home) in which TENS is applied compounds this difficulty of comparing results from different studies and underlines the need for systematic selection of optimal stimulating parameters within the context of randomised controlled trials.

6.3 Differences between clinical pain and experimental pain

There are inherent differences between clinical and experimental pain studies involving humans, and care must be taken when extrapolating the results of experimental pain studies to the clinical setting (Bromm, 1984; Gracely, 1994). Painful stimuli administered under laboratory conditions cannot duplicate the

physiological features of an acute or chronic pain condition, neither can they reproduce the accompanying psychological features such as anxiety and depression (Bromm, 1984). The usefulness of experimental studies is that external variables are easier to control than in the clinical setting and there is a pain stimulus of definable origin (Gracely, 1994). Any intervention used under laboratory conditions is also likely to show clinical efficacy, as well as possibly identifying the mechanisms of analgesic action (Gracely, 1994). There is, therefore, an important place in pain research for studies on healthy human volunteers, allowing information to be gained about the pathophysiology of pain and the efficacy of analgesics under controlled conditions. Researchers in the area of experimental pain have long been debating the qualities required of the ideal pain stimulus, the main qualities agreed being that it should be easily reproduced, quantifiable, and safe to administer (Bromm, 1984; Gracely, 1994; Procacci, Zoppi and Maresca, 1979). A pain stimulus possessing the required properties should, therefore, be able to provide information about the relationship between the stimuli being applied and pain reporting measures.

6.4 : Overview of human experimental pain induction methods

There are currently a number of experimental pain techniques being commonly used in human pain research. An overview of these techniques, under various headings indicating the type of stimulus used, will now be addressed.

6.4.1 : Chemical

The use of chemical methods for the induction of experimental pain covers various techniques, ranging from intracutaneous injection of hypertonic saline solution (Veerasarn and Stohler, 1992) and topical application of mustard oil (Ward, Wright and McMahon, 1996) to the more recently developed technique of applying carbon dioxide pulses to the nasal mucosa (Anton, Euchner and Handwerker, 1992). All the techniques share the similar problems of risking tissue damage (Handwerker and Kobal, 1993), difficulty in accurately quantifying the stimulus (Humphries, Long and Johnson, 1994) and the long refractory periods required between stimuli (Procacci et al, 1979). These reasons have led to a decrease in their use in favour of other pain induction methods.

6.4.2 : Mechanical

The oldest form of mechanical stimulation in human pain research involved an arrangement of pressure cuff in conjunction with pointed projections which impinged on the skin (Von Frey, 1894, in Handwerker and Kobal, 1993). Techniques favoured in more recent times involve the application of pressure directly to the skin. These techniques, when encompassing a spring-loaded gauge (pressure algometer), allow quantitative measures of the load being applied, therefore increasing reproducibility of stimuli (Brennum, Kjeldsen and Jensen, 1989; Jensen, Rasmussen, Pederson, Lous and Olesen, 1992).

Ultrasound stimulation has been used for the mechanical induction of pain on structures lying deep in the body (Wright and Davies, 1989). High energy ultrasound induces both thermal and mechanical stimulation to the tissues although the exact biophysical effects of this technique are not well understood. The unpredictable transfer of local energy prevents precise stimulus control and can cause damage to tissues (Handwerker and Kobal, 1993). A major criticism of this type of experimental pain induction is that mechanoreceptors, as well as nociceptors, are stimulated during the procedure (Humphries et al, 1994, Handwerker and Kobal, 1993). Another factor influencing the validity of the results with mechanical pain induction is that the effective compression varies according to the compliance of the underlying tissues and the speed at which the compression is carried out (Procacci et al, 1979).

6.4.3 : Electrical

Electrical stimulation is used widely in pain research, particularly for cutaneous stimulation (Procacci et al, 1979). This is most likely due to its qualities of being quantifiable and easily controlled (Gracely, 1994). The resistance provided by the skin can vary greatly and now, therefore, many stimulators have the facility to maintain a constant current throughout every variation of cutaneous resistance (Procacci et al, 1979). The problem offered by skin resistance has been addressed with the use of percutaneous electrical techniques but this method, as with transcutaneous techniques, has the drawback of stimulating a range of nerve fibres (e.g. non-noxious mechanoreceptors) and not just those associated with pain stimulation (Humphries et al, 1994; Handwerker and Kobal, 1993).

A number of studies have used electrical stimuli as a method of experimental pain induction when investigating the pain-relieving effects of TENS (Jette, 1986; O'Brien, Rutan, Sanborn and Omer, 1984). A form of electrical pain induction which has emerged in recent literature is the stimulation of tooth pulp. This procedure of pain induction is though to improve the selectivity of electrical stimuli as a more homogeneous group of afferent nerve fibres can be stimulated (Handwerker and Kobal, 1993) and tooth pulp stimulation has also been employed in previous TENS studies (Widerstrom, Aslund, Gustafsson, Mannheimer, Carlsson and Andersson, 1992). The main disadvantages of electrical stimulation have been considered to be its short duration and poor qualitative relationship with clinical pain (Humphries et al, 1994).

6.4.4 : Heat

Heat stimulation, like electrical methods, has been used widely for experimental pain induction. Heat stimuli can either be controlled by delivery from contact thermodes (Price, McGrath, Rafii and Buckingham, 1983), or by radiation (Arendt-Nielsen, Zacharie and Bjerring, 1990). Handwerker and Kobal (1993) suggested that thermodes and radiation devices were not necessarily comparable as the intracutaneous temperature varied depending on the wavelength, when heat was applied by radiation, or by the type of contact between thermode and skin. Laser beams are now frequently used as a form of experimental pain induction as they produce a rapid stimulus onset and provide uniform radiation (Gracely, 1994). Care must be taken, however, with powerful heating devices as fast rises in

skin temperature have been thought to excite sensitive mechanoreceptors in addition to warmth receptors and nociceptors (Handwerker and Kobal, 1993).

6.4.5 : Cold

Cold stimuli are most often applied to humans in experimental pain studies using the cold pressor method. This technique involves the subjects immersing their upper limb in water/ice baths and has the advantages of being repeatable and of prolonged duration. The cold pressor method has been used in trials involving TENS (Johnson, Ashton, Bousfield and Thompson, 1989). The authors found TENS current frequency to be the major determinant of stimulation-produced analgesia and reported that frequencies in the range 20-80Hz were most effective in relieving pain with this particular experimental pain model. The main disadvantage of the cold pressor method has been reported as being the long interstimulus interval required to achieve homeostatic equilibrium. This has been suggested as being due to the effects of the pain induction method on physiological variables such as blood pressure, blood flow rates, and vasomotor activity (Humphries et al, 1994; Handwerker and Kobal, 1993).

6.4.6 : Ischaemic

Ischaemic pain induction procedures vary slightly throughout the range of human experimental pain studies but are usually based on, to a greater or lesser degree, the submaximum effort tourniquet technique established by Smith, Egbert, Markowitz, Mosteller and Beecher in 1966. The technique has since been modified by other experimenters (Pertovaara, Nurmikko and Pontinen, 1984;

Roche, Gjisbers, Belch and Forbes, 1984; Woolf, 1979) but the basic concept involves the occlusion of blood flow to the upper limb using a pneumatic cuff, in conjunction with hand gripping exercises which are carried out whilst the limb is in the ischaemic state. If the limb is maintained at rest only ischaemic paraesthesia is achieved (tingling and numbness) and the muscular contractions are therefore required in order for the subject to experience pain (Procacci et al, 1979). Moore, Weissman, Thomas and Whitman (1971) put forward a number of recommendations concerning the gripping exercises in order to standardise the technique and reduce variability between subjects. It was suggested by the authors that the exercises should be carried out at a fixed percentage of maximal grip strength and the contractions carried out over a fixed duration.

The pain produced by the submaximal tourniquet test has been thought to be a result of a build-up of metabolites in the tissue spaces (Lewis, 1950, in Procacci et al, 1979). The author was reported to have stressed that allowing blood to return to the limb did not result in complete recovery of the tissues but instead the metabolites were reduced to a level that was not perceived as being painful. The same author (Lewis, 1942, in Keele and Neil, 1965) was reported to have found that this recovery time, which allowed pain to return to pre-test levels once circulation was returned, was between 2 and 4 seconds.

Another theory for the mechanism of experimental ischaemic pain and which may work in conjunction with the metabolite build-up is that ischaemia of nerve fibres causes an increase in their excitability. This would allow previously non-noxious

stimuli to reach noxious threshold values (Nathan, 1953, in Procacci et al, 1979). Yamada, Muroga and Kimura (1981) carried out a study which investigated somatosensory evoked potentials (SEPs) in nerves affected by ischaemia. The results of the study suggested that mechanical compression of the nerve induced ischaemic pain. Pertovaara et al (1984) identified that subjects exposed to the submaximal effort tourniquet test were able to distinguish between the exercise-induced metabolite arm pain and the pain caused by the cuff pressure.

Pain produced by this method of experimental pain induction has been found to be responsive to relatively small doses of pharmacological analgesics such as morphine and aspirin (Smith et al, 1966; Posner, 1984). Assessment of analgesic efficacy using this technique has been found appropriate as the stimulus is considered sufficient to produce an affective component which is associated with clinically significant pain, but is not usually found with short-lasting discrete stimuli (Gracely, 1994). The ischaemic model has also been used to test the efficacy of nonpharmacological treatments such as TENS (see Section 6.5). The variability in results that is obtained from analgesia studies may be due to a number of factors such as experimental error or the use of an inadequate stimulus but is most likely to be due to the mechanism of action of both the experimental pain model being employed and the modality being tested.

6.5 : Past studies using TENS with experimentally induced ischaemic pain (for summary of studies see Table 1)

An early study looking at human experimental pain and TENS was carried out by Woolf in 1979. The author employed various methods of pain induction, one of which was the ischaemic pain tourniquet technique. Eight healthy male subjects were used in a cross-over design, the two groups (n=4) acting both as a control (no TENS) and treatment group (TENS), the tests being one week apart. Woolf (1979) applied high frequency TENS (frequency 100Hz, pulse duration 250μs, intensity 'definite non-noxious paraesthesia') for 30 minutes prior to pain induction and during cuff inflation which was maintained until the subject reached their perceived pain tolerance level. The electrodes were applied over the median and ulnar nerves proximal to the cuff. Pain intensity VASs were marked by the subjects at one minute intervals during the pain induction period and these, as well as the pain tolerance time, were used as the outcome measures. No cross-over effect was found between the two groups and pain tolerance time was found to be increased from 12.9±1.6 minutes (S.E.; n=8; $p<0.001$) in the control group to 20.3±1.7 minutes (S.E.; n=8; $p<0.001$) in the group receiving high frequency TENS. A decrease in VAS pain intensity scores was also reported in the TENS group but no statistics were available to support these findings. The VAS outcomes should be regarded with caution as the VAS scores could have been dependent on the duration of the pain induction which was not consistent between subjects.

Table 1 : Past studies using TENS with experimentally induced ischaemic pain.

Authors	Subjects	Electrode Position	Experimental Design	Current Frequency (Hz) & Pulse Duration (μs)	Current Intensity (subject perception)	Frequency & Duration of Experiment	Outcome Measures	Results (*) significant findings (NS) non significant findings
Walsh et al (1995)	n =32 (all female) University staff / students TENS / experiment naive	C6 / 7 & Erb's point	4 groups (random) n = 8 (1) control (2) placebo (3) TENS 1 (4) TENS 2 double-blind conditions	(TENS 1) 110, 287 (TENS 2) 4, 287	"strong but comfortable"	tested twice (48 hours apart) 1st - baseline 2nd - treatment duration = 10 minutes before pain + 12 minutes during test	VAS - pain intensity 1 minute intervals during test MPQ - end of test	VAS scores - group (TENS 2) (*) ANOVA p=0.02 MPQ scores - trend towards group (TENS 2) (NS)
Foster et al (1995)	n=48 (24 male,24 female) age range 18-39 mean age 19.4 healthy, TENS-naive	C6 / 7 & Erb's point	6 groups (random) n=8 (1) control (2) placebo (3) TENS 1 (4) TENS 2 (5) TENS 3 (6) TENS 4 double-blind conditions	(TENS 1) 110, 200 (TENS 2) 110, 50 (TENS 3) 4, 50 (TENS 4) 4 , 200	"strong but comfortable"	tested twice (48 hours apart) 1st - baseline 2nd - treatment duration = 30 minutes (starts 23 minutes prior to test)	VAS - pain intensity 1 minute intervals during test MPQ - end of test	VAS and MPQ - trend towards group (TENS 4) (NS)
Walsh et al (1993)	n=46 healthy volunteers	C6 / 7 & Erb's point	5 groups (random) (1) control (2) TENS treatment (3) TENS placebo (4) H-wave treatment (5) H-wave placebo	(TENS) 4, 287 (H-wave) 60Hz, 17.1ms	"strong but comfortable"	tested twice (48hours apart) 1st - baseline 2nd - treatment duration = 22 minutes (starts 10 minutes prior to test + 12 minutes during)	VAS - pain intensity 1 minute intervals during test MPQ - end of test	VAS scores - H-wave > TENS (*) ANOVA p<0.001 MPQ scores - H-wave > TENS (*) ANOVA p<0.05

Authors	Subjects	Electrode Position	Experimental Design	Current Frequency (Hz) & Pulse Duration (μs)	Current Intensity (subject perception)	Frequency & Duration of Experiment	Outcome Measures	Results (*) significant findings (NS) non significant findings
Roche et al (1984)	n=48 (24 male,24 female) mean age = 24	radio-ulnar joint & cubital fossa	4 groups (random) (1) control (2) TENS 1 (3) TENS 2 (4) TENS 3	(TENS 1) 100, 1000 (cont) (TENS 2) & (TENS 3) 5,1000 (burst duration of 100ms)	(TENS 1) & (TENS 2) "high but non-noxious" (TENS 3) "just feel a pricking sensation"	tested once duration = maximum of 35 minutes (starts 10 minutes prior to test)	pain threshold and pain tolerance levels VAS - pain intensity & PPI (5 point) at 1 minute intervals during test MPQ - end of test	pain threshold (TENS3)>(TENS 2) (*) 2-tailed t-tests $p<0.02$ (TENS 3)> (TENS 1) (*) $p<0.05$ pain tolerance (TENS1) > control group (*) $p<0.01$ VAS - (NS)
Woolf (1979)	n=8 (all male) healthy students age range 19-22	over median and ulnar nerves proximal to cuff	2 groups (random) cross-over design (n=4) (1) control (2) TENS	(TENS) 100, 250	"definite non-noxious paraesthesia"	tested twice (1 week apart) duration = 30 minutes prior to test + during test (to tolerance)	pain tolerance level VAS pain intensity - 1minute intervals during test	no cross-over effect increase in pain tolerance (TENS) group (no stats) decrease VAS scores (TENS) group (no stats)

Roche et al (1984) used variations in stimulation parameters when investigating the pain-relieving effect of TENS on experimental ischaemic pain. Forty-eight healthy volunteers (24 male, 24 female, mean age 24) were randomly assigned to one of four groups (1 control group and 3 TENS groups). Each subject was tested only once and, in the groups receiving TENS, electrodes were applied over the radio-ulnar joint and cubital fossa of the affected arm 10 minutes prior to starting pain induction. The electrodes delivered current throughout the pain induction period which lasted for 25 minutes. The three treatment parameters of TENS were (1) frequency 100Hz, pulse duration 1000μs (continuous current), intensity 'high but non-noxious'; (2) frequency 5Hz, pulse duration 1000μs (burst current of duration 100ms), intensity 'high but non-noxious'; and (3) frequency 5Hz, pulse duration 1000μs (burst current 100μs), intensity 'just feel a pricking sensation'. Outcome measures included measuring pain threshold and pain tolerance times, as well as marking a pain intensity VAS and present pain intensity (PPI) 5-point VRS at one minute intervals during pain induction. Each subject also completed the McGill Pain Questionnaire (MPQ) at the end of the test. Two-tailed t-tests showed TENS (3) to have a significant effect on pain threshold while TENS (2) was found to be significantly greater than the control group when comparing tolerance times. No significant differences was found between the groups using the VAS pain intensity scores. The only difference between the TENS (2) and TENS (3) was the current intensity with all the other current parameters remaining the same. The results suggest that the 5Hz current was more effective than the 100Hz current in decreasing pain perception, regardless of the current intensity selected.

Walsh, Liggett, Baxter and Allen (1993) compared the treatment and placebo pain-relieving effects of low frequency TENS and H-wave therapy (a form of electrical stimulation similar to TENS but possessing a double-spiked stimulus) using the ischaemic model of experimentally-induced pain. Forty-six healthy volunteers were randomly assigned to one of five groups and were tested twice with 48 hours between the tests. The first test was used to gather baseline data (no TENS) while in the second test each subject received their appropriate TENS combination (TENS treatment 4Hz frequency, 287μs pulse duration, 'strong but comfortable' intensity; TENS placebo machine switched on but no current). Stimulation began 10 minutes before pain induction and lasted throughout the 12 minutes of the test. In each case the electrodes were placed lateral to C6/7 and over Erb's point on the affected side. Subjects marked a pain intensity VAS at one minute intervals during pain induction and completed the MPQ at the end of the test. The pain-relieving efficacy of the selected interventions was established in each case by comparing the pain scores (VAS intensity and MPQ) obtained for the two tests (1-way ANOVA and difference scores). Analysis of results using an ANOVA showed H-wave therapy at the chosen parameters as having a significantly greater pain-relieving effect than the other treatment applications, as assessed using pain intensity VASs and the MPQ (PPI score). This study used the outcome of the 1st test as a measure on which to base the effectiveness of each intervention. The assumption was therefore made that the pain reporting in the 1st exposure to the test produced stable baseline values. It has been identified in the literature that a large number of psychological variables, including subject mood state and patient-therapist interaction, can influence pain perception (Gielen,

1989; Klaber Moffett and Richardson, 1997; Turner et al, 1994). It is therefore a possibility that making direct comparisons between 2 sets of pain scores, as done in this study, did not accurately reflect the pain-relieving efficacy of each treatment intervention.

A similar study design was selected by Walsh et al (1995) when they compared the pain-relieving effects of high frequency and low frequency TENS. Thirty-two female volunteers were randomly assigned to one of four groups (n=8). As before, subjects were tested twice to initially collect baseline data. Treatment with TENS was dependent on group allocation; group 1 (control - no TENS), group 2 (placebo - no current), group 3 (frequency 110Hz, pulse duration 287μs, intensity 'strong but comfortable') or group 4 (frequency 4Hz, pulse duration 287μs, intensity 'strong but comfortable'). Electrode placement and pain assessment procedure was the same as for the previous study. A one-factor ANOVA showed a significant difference in VAS scores between the groups and a follow-up Fisher test indicated that the low frequency TENS produced a significantly greater pain-relieving effect than the other treatments using the same outcome measure. No significant difference was found between the groups using the MPQ scores. As for the study carried out by Walsh et al (1993), the experimental design used in this study may not have allowed for an accurate reflection of the pain-relieving efficacy of each treatment intervention.

Another study based on a similar design as Walsh et al (1993) was carried out by Foster, Walsh, Baxter and Allen in 1995. Fort-eight healthy subjects (24 male, 24

female, age range 18-39, mean age 19.4) were assigned to one of six groups. The experimental design was as before except the TENS parameters consisted of combinations of pulse frequencies 110Hz and 4Hz, and pulse durations 200μs and 50μs. Pulse intensity remained the same in each case as 'strong but comfortable'. Electrodes were placed over C6/7 and Erb's point and TENS stimulation was experienced by the subjects for a total of 30 minutes (applied 23 minutes prior to pain induction). Pain assessment followed the same procedure as the studies conducted by Walsh et al (1993, 1995). Results showed no significant difference between the groups in either VAS or MPQ scores, however the authors suggested a trend towards the 4Hz, 200μs TENS combination as the optimal pain-relieving parameters.

The results of the reviewed studies did not unequivocally support a given set of TENS parameters as producing a pain-relieving effect on healthy volunteers using the ischaemic experimental model of pain. The variations found between the studies for both the pain induction procedure (gripping exercises, pain duration), and TENS application (electrode placement, current parameters, control of current intensity, timing of application relative to pain induction) makes it difficult to draw any definite conclusions from the findings. The outcome of the study by Roche et al (1984), however, did suggest that the current frequency could have influenced pain perception and the difference in pain-relieving effect between current frequencies was further highlighted in the studies by Walsh et al (1995) and Foster et al (1995). The study outcomes, although suggesting that low frequency currents had a greater pain-relieving effect than high frequency currents

on experimental ischaemic pain, were still inconclusive and warrant further investigation.

6.6 : Conclusions

(1) TENS is used with a wide range of clinical pain conditions. The outcomes of clinical trials investigating the efficacy of TENS are inconclusive and this is probably due to the large number of differences in variables between studies and the outcome measures used.

(2) Experimental pain induction is used in human pain studies to reduce the number of variables. The ischaemic method of pain induction has been a popular choice with past experimenters investigating the efficacy of TENS.

(3) Past studies using the experimental ischaemic pain model have found current frequency to be a possible variable influencing pain perception during the application of TENS.

CHAPTER 7 : THE ASSESSMENT OF PAIN

7.1 : Introduction

Pain has long been recognised as a multidimensional experience, a view supported by neurophysiological evidence (Fields, 1987; Guilbaud et al, 1994; Jones, 1997; Lima, 1997; Wade et al, 1996), but this has not always been reflected in the measurement of the pain response. Pain can be considered as being made up of two principal measurable components, sensory and affective (Gracely, 1994; Gracely, McGrath and Dubner, 1978; Price and Harkins, 1992) which has already been identified in Chapters 3 and 4. The sensory component of pain is activated by ascending noxious information in the lateral systems and is primarily concerned with the physical nature of the pain, such as the location, intensity, duration, and quality of the sensation (Guilbaud et al, 1994; Jessell and Kelly, 1991; Jones, 1997). The affective component, on the other hand, is activated by ascending noxious information in the medial systems and deals with the degree of discomfort or

unpleasantness which is associated with the physical pain sensation (Guilbaud et al, 1994; Jessell and Kelly, 1991; Jones, 1997). Gracely (1994) stated that single measures of pain magnitude create confusion as the underlying meaning of the pain magnitude is unknown and suggested that the confusion could be minimised by employing scales that essentially ask "how intense is your sensation, and how much does it bother you". The aim of this chapter is to review assessment tools which are multi-dimensional in nature and, with particular relevance to the present study, have been employed using the ischaemic model of experimental pain induction.

Several studies have identified intensity and unpleasantness as two distinct components of the pain response in both clinical (Marchand et al, 1993; Leavitt, Garron, Whisler and Sheinkop, 1978), and experimental (Duncan, Bushnell and Lavigne, 1989; Price, Von der Gruen, Miller, Rafii and Price, 1985) pain trials. Price et al (1985) exposed 47 volunteers to four graded intensities of experimentally induced heat pain. The authors found that responses to pain intensity and pain unpleasantness were both reduced by intravenous administration of morphine sulphate in a dose-dependent manner. A different intravenous analgesic, fentanyl, was used by Gracely, Dubner and McGrath (1979). Perceived pain levels of electrical stimulation of tooth pulp (n=40) were measured before and after drug intervention, with the results showing that fentanyl significantly reduced the intensity, but not the unpleasantness, of the painful stimuli. The findings indicate that the components of the pain response can alter independently of each other when pain-relieving treatments are introduced and highlights the need to measure pain intensity and pain unpleasantness separately.

7.2 : Pain measurement techniques

Three types of methodology which have been found capable of assessing the multiple pain dimensions during experimental pain studies are; (1) the multidimensional scaling of experimentally-induced pain sensations in order to determine the dimensions of a scale, (2) the multidimensional scaling of verbal descriptor items in order to construct or validate the structure of an existing scale, or (3) the use of existing scales to assess experimentally-induced pain sensations (Gracely, 1994).

It has been thought beyond the scope of this thesis to develop a measurement tool specific to the experiments being undertaken, and instead approach (3) will be adopted. This approach makes it easier to compare previous investigations in this topic area with the present study and eliminates the need of establishing the validity and reliability of a new pain assessment tool.

A wide range of pain assessment techniques have been employed with the use of clinical TENS trials (see Section 6.2) and, within the specific area of TENS and experimental ischaemic pain, a number of measurement tools stand out as being commonly used (see Section 6.5). Walsh et al (1995) identified two types of pain estimation that require individual attention whilst investigating the pain-relieving effects of TENS using the ischaemic model of experimental pain. The authors described these measures as being the 'current level of pain' experienced (assessed at regular intervals during the pain induction period) and the 'worst pain' experienced (measured immediately after the painful stimulus has been removed).

The review of TENS studies which have used the experimental ischaemic pain model (see Section 6.5) indicated that investigations in this particular research area have, without exception, selected a unidimensional approach to 'current level of pain' assessment. The limitations of this form of pain assessment have been highlighted (see Section 7.1) and therefore only scales which are well recognised and established multidimensional pain measures will be reviewed.

Two types of scale which can be adapted to rate both present pain intensity and present pain unpleasantness are the visual analogue scale (VAS) and the verbal rating scale (VRS). The McGill Pain Questionnaire (MPQ) is a multidimensional pain assessment tool which has been considered appropriate for measuring the 'worst pain' experienced (Walsh et al, 1995). Each of the three scales will be considered in more detail below.

7.2.1 : The visual analogue scale (VAS)

A VAS takes the form of a line, usually 10 centimetres long, with the ends of the line labelled as the extremes of pain. The anchors used are reflective of the component of pain being assessed. For example, the minimum scale anchor could be 'no sensation' for pain intensity, or 'not bad at all' for pain unpleasantness. The subject is asked to rate their pain by marking the scale at some point along its length. The distance (usually expressed in millimetres) from the minimum anchor is given as a measure of the subject's pain response.

There is much evidence supporting the validity of the VAS as a measure of both components of pain in clinical and laboratory settings (Price, Harkins and Baker, 1987; Price et al, 1983; Price et al, 1985). The scale is also thought to produce data that has interval / ratio qualities and can therefore be treated as such statistically (Waterfield and Sim, 1996; Price et al, 1987; Price et al, 1983). It should be emphasised that not all types of VAS are bias-free and it has been suggested that the sensitivity and reliability of the VAS are influenced both by the length of the line and the anchors applied to it (Seymour et al, 1985, in Jensen and Karoly, 1992; Sriwatanakul, Kelvie, Lasagna, Calimlim, Weis and Mehta, 1983). Seymour et al (1985), in Jensen and Karoly (1992), found that scales in the length range 10 to 15 centimetres and employing words that best described the extremes of the pain sensation were least susceptible to biases in scoring.

Scale orientation has also been raised as a factor affecting scale reliability, with Sriwatanakul et al, (1983) finding that vertical scales were less normally distributed, and had a greater coefficient of variation than an identical scale placed horizontally. Brevik, Haanaes and Skoglund (1996), however, found dissimilar results using a patient population (n=93) with dental pain. The scores obtained from the two 10 centimetre long scales were found to correlate highly with one another ($r=0.97$, $p=0.0005$). The former study enrolled healthy volunteers and the scales were marked by comparison to six verbal descriptors of pain intensity which were called out by the experimenter. The pain-free status of the population employed in the study carried out by Sriwatanakul et al (1983) questions the validity of the results

and it remains a matter of debate whether VAS orientation, indeed, has any bearing on the scale's ability to produce reliable data.

The main disadvantages of the VAS could be seen as being the two steps required in its marking (marking by the subject and measuring by the experimenter), which may introduce a source of error to the procedure (Jensen and Karoly, 1992). The same authors also suggested that certain subject groups, such as the elderly, may find the scale confusing due to its lack of structure. The scale's advantages, however, are that it is economical, easy to administer, and provides a wide range of response categories (Jensen and Karoly, 1992; Jensen, Karoly and Braver, 1986).

7.2.2 : The verbal rating scale (VRS)

The VRS uses a list of adjectives describing different levels of pain, including adjectives which reflect the extremes of the particular pain component. For example, 'no sensation' and 'the most intense sensation imaginable' for pain intensity. As with the VAS, the words used are reflective of the component of pain being assessed. The number of adjectives listed for each pain component can vary between scales, although a number between 4 and 15 is usual (Jensen and Karoly, 1992). The VRS, in its basic format, takes the form of a ranked ordinal scale, with each adjective being assigned a score as a function of its rank (Jensen and Karoly, 1992). The major criticism which this type of scale frequently receives is that it assumes equal intervals between the adjectives which, of course, is unjustified. The VRS, if treated correctly as a category scale, yields ordinal data with qualities unsuitable for parametric statistical analysis. This makes the scale less attractive for use in studies

as non-parameteric statistical tests carry less statistical power and require fewer assumptions about the data than their parametric equivalents (Payton, 1994).

Cross-modality matching is a procedure which can transform the VRS into a scale more likely to have interval/ratio properties (Duncan et al, 1989; Gracely et al, 1978). The procedure involves matching each adjective with another modality such as the loudness of a tone or handgrip force (Jensen and Karoly, 1992), and provides relatively bias-free interval/ratio data which allows parametric analyses of the subjects' responses (Duncan et al, 1989). Cross-modality matching can be a time-consuming procedure and one way around this problem is to assign standardised scores for each word based on data from groups of previously tested individuals (Duncan et al, 1989; Gracely et al, 1978). This technique has been considered appropriate as long as a comparable population is selected, taking into consideration the type of pain stimulus (clinical or experimental) involved (Jensen and Karoly, 1992).

The strengths of VRSs include the ease with which they are administered and scored. Also, compliance with this form of scale has been found to be higher than that found with other measurement tools such as a VAS and a numerical rating scale (similar to a VAS except with numerical graduations) (Jensen et al, 1986). The weaknesses of the scale, on the other hand, have been reported as including the sometimes small number of category responses available to subjects and the literary skills required by the subjects in order to understand the meanings of the adjectives listed (Jensen and Karoly, 1992). The use of language in a scale automatically makes

it susceptible to error due to the fact that individuals in a group of subjects are likely to interpret the same pain descriptor differently (Jensen et al, 1986; Chapman, Casey, Dubner, Foley, Gracely and Reading, 1985).

7.2.3 : VAS versus VRS

Comparisons have been made between the VAS and VRS as pain assessment tools, with Merskey (1974) comparing a 5 point VRS, which had undergone a procedure of cross-modality matching (loudness of a tone), with a 10cm long VAS. The author reported a high correlation between the scales ($r>0.8$, $p<0.01$, no other statistical details given), and this corresponds with the findings of a later study carried out by Roche et al (1984). Forty-eight subjects were exposed to a maximum of 25 minutes of experimental ischaemic pain, during which time the subjects were asked to rate their pain intensity on both a VAS and a 5 point VRS at one minute intervals. The correlations between these scales for individual subjects were found to be significant at a $p<0.05$ level (no other statistical details given). No information is given as to how the data from the scales were compared and the results should be viewed cautiously as the comparison involves data from both an ordinal and an interval/ratio scale. Wallenstein, 1984 (in Bromm, 1984) used, among other methods, power functions to compare pain intensity scores marked on a 10cm VAS and a 5 point VRS in a group of 35 cancer patients. The correlation between the scales, in terms of a power curve, was quite high ($r=0.89$) and were found not to be influenced by age or sex within the population.

Ohnhaus and Adler (1975) used both a 10cm VAS and a 5 point VRS to assess the analgesic efficacy of pharmacological medications used in the treatment of patients with cancer pain. Six patients (2 female, 4 male, mean age 54 years) suffering from relatively constant pain due to malignant disease with metastases were exposed to 3 treatment conditions (2 types of drug, 1 placebo). The 3 treatment days were at least 24 hours apart and the drugs were given in a randomised order. Patients were asked to rate their pain intensity on both scales immediately before each treatment session and then at 30, 60, 120, and 180 minutes after the treatment had been given. The correlation between the two scales was found to be highly significant ($r=0.81$, $p<0.001$) but the VRS data was converted into a digital system in order to carry out the comparison. The median descriptor in the scale was issued a score of 0, while descriptors adjacent were valued + or - 1 accordingly. The extreme descriptors were valued + or - 3. The authors correctly felt that this inappropriate handling of an ordinal scale with interval-type assumptions, resulted in an artificial measurement of effects by the analgesics. The authors therefore concluded that the VAS used in their study assessed more closely what a patient actually experiences with respect to change in pain intensities.

A study which identified the multidimensional nature of pain and compared verbal and visual analogue scales for measuring both pain intensity and pain unpleasantness was carried out by Duncan et al (1989). Eight healthy volunteers (4 male, 4 female; age range 21-26) were asked to rate the intensity and unpleasantness of thermal stimuli, using either a VRS (11 point intensity, 9 point unpleasantness) or a 10cm horizontal VAS (intensity anchors 'no sensation' and 'the most intense that one

could imagine'; unpleasantness anchors 'not bad at all' and 'the most unpleasant imaginable'). The heat stimuli consisted of 6 different intensities (42-51°C) via a skin contact thermode, each presented 6 times 25 seconds apart. Each type of scale (VAS intensity, VAS unpleasantness, VRS intensity, and VRS unpleasantness) was presented twice consecutively but the order in which the subjects received them was randomised. The VRS scores assigned to all the pain descriptors were from standardised cross-modality matching scores from a previous experiment (Duncan, Duquette and Bushnell, 1985). In this earlier study 90 healthy volunteers were asked to rank order lists of frequently-used pain intensity and pain unpleasantness descriptors and then rate the relative magnitude of each descriptor using a VAS. Duncan et al (1989) reported no significant differences between the two types of scales being compared (intensity $p>0.93$; unpleasantness $p=0.17$; no other statistics given) but these results were only to be expected as the pre-assigned VRS scales had been matched with VAS scores. This procedure marked a major flaw in the methodology of the study and may have influenced the validity of the results obtained.

The review of papers which have compared the VRS and VAS indicate that the two scales produce significantly similar data in both laboratory and clinical settings. An attempt has also been made to demonstrate the multidimensional qualities of the scales (Duncan et al, 1989; Duncan et al, 1985), as well as their ability to assess analgesic efficacy (Ohnhaus and Adler, 1975). Care should be taken when statistical analyses of the VAS and VRS are being carried out, particularly with regards to the latter - the VRS is an ordinal scale which cannot assume equal numerical distance

between its various descriptors. It has not been possible to state which of the two scales is most appropriate for any given research experiment and it should be noted that the statistical power of the tests in the two main studies (Duncan et al, 1989; Ohnhaus and Adler, 1975) were limited due to the small subject numbers used. The success of either scale is dependent on what exactly is being measured, as well as the subject group marking them. It appears necessary to initially use both scales in conjunction, and then consider their relative strengths and weaknesses.

7.2.4 : The McGill Pain Questionnaire (MPQ)

The MPQ is a self-report instrument that presents subdivisions of pain descriptors, organised into 3 main categories (sensory, affective, and evaluative). The major measures which can be achieved from the MPQ are the pain rating index (PRI) (individual score from each category or an overall total score), the number of words chosen (NWC) from the list of descriptors, and a present pain intensity (PPI) score based on a 1-5 intensity category scale.

The MPQ was originally devised as a multidimensional pain assessment tool for use in the clinical setting, with literature supporting the scale's ability to distinguish between different types of clinical pain (Melzack, 1975; Melzack and Katz, 1992). The MPQ, as with all other pain measures, has its limitations. Wolf, Gersh and Rao (1981) used the MPQ with 114 patients with chronic pain and reported that a large proportion of the patients were unable to understand many of the descriptors listed in the scale. For this reason PRI scores were not found to be accurate reflections of the patient's pain experience and a poor correlation was found between the various

PRI scores and the figure achieved in the simpler PPI category scale. A recent study carried out by Fernandez and Towery (1996) identified a number of descriptors within the MPQ which were considered inappropriate due to their ambiguity and suggested that the scale needs to be refined in order to increase its validity.

The MPQ has also been tested in the laboratory setting, with Chen, Dworkin and Gehrig (1989) finding the scale repetitively consistent over five studies using the cold pressor method of pain induction. Walsh et al (1995) employed the MPQ to assess the pain-relieving effects of TENS during experimental ischaemic pain. The MPQ was scored by the subjects (n=32) at the end of the test, with the results showing no statistically significant changes in any of the PRI scores during the TENS application. During the same study, the subjects were presented with VAS intensity scales at one minute intervals during the pain induction period. Unlike the MPQ scores, the reduction in VAS scores was found to be statistically significant with TENS intervention. The authors accepted that the discrepancy in the two scales' findings may be due to poor recall of the pain experience when marking the MPQ. The memory for experimental ischaemic pain was examined by Roche and Gijsbers (1986) and it was reported that the affective component of the MPQ is particularly susceptible to recall inaccuracy. This finding underlines the necessity to assess both sensory and affective components of pain during the period of pain induction.

7.3 : Conclusions

(1) It has been recognised, based on the neurophysiological evidence for a multi-dimensional pain response, that pain measures should assess both pain intensity and pain unpleasantness.

(2) Treatment interventions have been found to selectively alter the components of the pain response.

(3) Past studies involving TENS and the experimental ischaemic pain model have only assessed pain intensity during pain induction, with the MPQ being employed as a multi-dimensional pain assessment tool after the cuff has been deflated.

(4) The VAS and VRS have been identified as scales which can be adapted to assess 1st stage pain intensity and pain unpleasantness.

7.4 : Summary of the review of literature and implications for the present study

The aim of the review of literature is to highlight the theoretical building blocks of the thesis and to establish the current state of knowledge in these areas. The review of the literature, therefore, identifies gaps in the body of knowledge and carries implications for the experimental procedure of the present study. The key points that have been raised by the review of literature and the implications that they had for the present study are as follows:

7.4.1 : Model of pain induction

TENS has been established as a pain-relieving modality which operates through the stimulation of peripheral nerve fibres. It is used for a variety of different clinical pain conditions but the efficacy of TENS is still in question due to varied and often contradictory study outcomes. This difference in study outcomes can be attributed to the wide number of variables between the studies including the selected current parameters of TENS, the environmental context of the treatment and the type of patients being used. A way of reducing the number of external variables in a human pain study is by using an experimental model of pain induction. The review of experimental pain methods, although recognising the strengths of each of the other models, resulted in the ischaemic model being selected. There were various reasons as to why the ischaemic pain model was selected in preference over other pain induction techniques and these included (i) possession of a standardised procedure which theoretically allowed the painful stimulus to be easily reproduced (based on the sub-maximal ischaemic tourniquet test initially standardised by Moore et al

(1971), (ii) the ability of the model to produce a painful stimulus which could be tolerated over a prolonged period of time (Pertovaara et al, 1984) and (iii) a short recovery period (Lewis, 1942, in Keele and Neil, 1965 was reported as noting that once circulation was returned to the ischaemic limb a time period of 2-4s allowed pain to return to pre-test levels).

7.4.2. : Subject group

The ability of a subject to control a stimulus is a variable which has been found to affect pain perception but to date no work has been published investigating the influence of control on pain perception during the use of TENS. Neurophysiological evidence has suggested that control could have an effect on both the first and second phase of pain perception, in the first stage influencing both the sensory-discriminative and the motivational-affective components of the pain response. The present study investigated one aspect of control specific to TENS, the influence of experimenter and subject control of the current intensity on pain perception. Healthy undergraduate students from Queen Margaret College were used as subjects in the present study as, theoretically, a psychological variable such as control was easier to manipulate with students on medically-related courses familiar with the experiment, test environment and physiotherapy procedures in general. In this way attentional mechanisms and placebo effects should have been minimised or at least maintained at a comparable level between subjects.

7.4.3 : Experimental design

A repeated measures experimental design was used in the present study with each subject being tested on three separate occasions approximately 48 hours apart. The time between testing sessions was based on previous studies carried out using the ischaemic pain tourniquet test (Foster et al, 1995; Walsh et al, 1993; Walsh et al, 1995). The three conditions under which each subject was tested were (i) pain induction + TENS where the subject controlled the current intensity (ii) pain induction + TENS where the experimenter controlled the current intensity and (iii) pain induction without TENS. The ordering of the three conditions was carried out using a Latin Square design to minimise any possible carry-over effects of treatment and then subjects were randomly assigned to each ordering combination.

No placebo or sham TENS condition was incorporated in the present study due to the subject group being used (see Section 7.4.2). The subjects being used in the present study were undergraduate students from medically-related courses at Queen Margaret College, primarily Physiotherapy. The subjects were therefore familiar with TENS and the sensations that it produces. The inclusion of a placebo group in the present study, taking into consideration the repeated measures design, could have decreased the validity of the results. In such a case the subjects would have experienced both the active and sham TENS and, based on their knowledge of TENS and the sensations that they would have expected to be produced, the subjects would have been likely to have then perceived the effectiveness of the modality to have been different in each case. This in turn may have led them to mark their pain scales differently. On the basis of this argument no placebo condition was

included in the present study. A no treatment control condition was seen to be useful for inclusion in the present study as then comparisons could be made between pain responses when subjects received TENS treatment under both subject and experimenter control conditions and pain responses when no TENS was applied at all.

7.4.4 : Current intensity

Previous studies which have investigated the efficacy of TENS using the ischaemic model of experimental pain induction have found frequency to play a role in outcome success. The influence of experimenter and subject control of the current intensity on the pain-relieving efficacy of both a high frequency (100Hz) and low frequency (5Hz) TENS current was investigated in the present study.

With both high and low frequency TENS a low current intensity ('just perceptible') was used. This selection was based on neurophysiological research which proposed that, at current intensities less than 6-7 times greater than sensory threshold, TENS operates through the stimulation of peripheral Aβ fibres (Levin and Hui-Chan, 1993). The stimulation of Aβ afferent fibres has been associated with the activation of spinal segmental mechanisms (Garrison and Foreman, 1994; Melzack and Wall, 1965), with higher intensities of current stimulating nociceptive Aδ and C fibres through supraspinal mechanisms (Sjolund and Eriksson, 1979). The choice of TENS current intensity in the present study was therefore made to theoretically minimise the level of neural processing at brainstem, and particularly, cortical level. In this

way it was considered that the effect of control of the TENS intensity was not masked by neurophysiological mechanisms activated directly by the TENS current.

The psychological variables of control have been found to influence 1st stage pain perception through the stimulation of target sites such as the cingulate gyrus and the temporal lobe (Jessell and Kelly 1991; Jones, 1997) and, to a greater extent, 2nd stage processing through higher level neural processing in the association cortices (Guilbaud et al, 1994; Jones, 1997). Maintaining TENS current intensities at a level which are thought to selectively activate spinal segmental mechanisms therefore theoretically reduced the possibility of interference between mechanisms activated directly by the TENS current and those activated by the variable of control.

7.4.5 : Pulse duration and electrode placement

A pulse duration of 200μs was selected with both high and low frequency TENS currents in the present study as it represented a mid value in the parameter range most frequently used in the clinical setting (Kahn, 1994) and was similar to those selected by experimenters who have carried out TENS studies using experimental ischaemic pain induction (Foster et al, 1995; Walsh et al, 1993; Walsh et al, 1995; Woolf, 1979). Parameter selection in past ischaemic pain studies (Foster et al, 1995; Walsh et al, 1993; Walsh et al, 1995) was also a principle determinant in the choice of electrode placements in the present study as, in order to compare and contrast the results of the present study with those carried out previously, it was preferable to maintain similar current parameters as to those already investigated.

7.4.6 : Pain assessment

An important aspect of the present study was the decision to use a multi-dimensional approach to the assessment of pain perception during the induction of experimental pain. The decision to assess pain intensity and pain unpleasantness during the pain induction period was based on the neurophysiological evidence for there being two distinct components of initial (1st stage) pain processing, sensory-discriminative and motivational-affective, activated by ascending noxious information in the lateral and medial ascending systems respectively (Fields, 1987; Guilbaud et al, 1994; Jones, 1997; Lima, 1997). Pain perception during pain induction, and not after removal of the painful stimulus, was assessed in the present study because of the subject group being used and the neurophysiological evidence for different stages of pain perception. It has been suggested that the perception of pain occurs in 2 stages, with an immediate reaction (sensory-discriminative and motivational-affective components), followed by a later (2nd) stage of pain perception which is influenced to a much greater extent by cognitive appraisal (cognitive-evaluative component) (Price and Harkins, 1992; Wade et al, 1996). It has been recognised that experimental pain cannot reproduce psychological features typical of clinical pain such as anxiety or depression (Bromm, 1984) and therefore assessment of 2nd stage pain perception in the present experimental pain study was considered to be of limited relevance.

Chapter 8 : Experiment 1 - A comparison of a visual analogue scale (VAS) and a verbal rating scale (VRS) as assessment tools of pain intensity and pain unpleasantness using the ischaemic pain tourniquet test on healthy female volunteers.

8.1 : Introduction

The assessment of pain has been reviewed (see Chapter 7) and it has been established that it involves the recording of a subjective experience which is multidimensional in nature (see Section 7.1). The principal criteria for an ideal pain assessment procedure have been listed by Price and Harkins (1992) and include being able to separately measure the sensory-discriminative (pain intensity) and affective (pain unpleasantness) aspects of pain. These dimensions of the pain experience were explicitly recognised by Melzack and Casey in 1968 (see Section 3.4) and take into consideration that the perception of a noxious stimulus is associated with activity in separate neurophysiological pathways corresponding to

both sensory-discriminative and motivational-affective responses to pain (Fields, 1987; Guilbaud et al, 1994; Jones, 1997). Affective responses to pain are, therefore, a primary response to noxious stimulation and can be assessed at the same time as pain intensity. The sensory-discriminative and affective components of pain may co-vary in both clinical and experimental conditions but treatment interventions such as TENS have the ability to selectively alter either or both of the pain components (see Section 7.1). It is therefore important to measure both components of pain (intensity and unpleasantness) separately.

Two scales which have been adapted to separately measure pain intensity and pain unpleasantness are the visual analogue scale (VAS) and the verbal rating scale (VRS) (see Sections 7.2.1 - 7.2.3). Both types of scale have been used with the ischaemic experimental model of pain but to date have only been used to measure pain intensity (see Section 6.5 and Table 1).

The specific characteristics of the VASs used in this study were based on adaptations of validated pain intensity and pain unpleasantness VASs described by Jensen and Karoly (1992) and Price et al (1983). Both VASs were 10cm in length, horizontal in orientation and possessed no graduations along their length. The anchors for the pain intensity scale were 'no sensation' and 'the worst sensation imaginable' while the pain unpleasantness scale had 'not bad at all' and 'the worst sensation imaginable'. In each case the minimum anchor was at the left hand side of the scale (see Appendix 9).

The VRSs used in this study were taken from a study carried out by Duncan et al in 1985. The authors translated from English to French two lists of words previously validated for measuring pain intensity and pain unpleasantness (no reference given). Two groups of healthy subjects (70 dental students and 20 dentists) separately rank-ordered the two lists of words and rated the relative magnitude of each descriptor by comparing it to a line length on a VAS (cross-modality matching). Intra-subject and inter-subject reliability for both scales were found to be high ($r \geq 0.99$). Both Duncan et al (1989) and Gracely et al (1978) reported that using previously-assigned cross-modality matching scores from a comparable population is appropriate and, indeed, the original devisors of the VRSs used them in a later study (Duncan et al, 1989) and found a high correlation between the VAS and VRS when used with healthy French volunteers experiencing experimental heat pain (see Section 7.2.3). The cross-modality matching procedure gives the VRS interval / ratio scaling properties and therefore allows parametric statistical analysis of the results (Payton, 1994).

The pain intensity and pain unpleasantness VRSs contained 11 and 9 pain descriptors respectively. The scores for both VRSs ranged from 0 to 100, with the phrases at either extreme of the scale being the same as the anchor phrases used for the VASs (see Appendix 9). The difference between pain intensity and pain unpleasantness was explained to the subjects before marking the scales and an analogy written by Price et al (1983) was used. The analogy asked the subjects to think of listening to a sound, such as the radio, and then distinguish between how loud the sound is (intensity) and how unpleasant it is to hear it (unpleasantness).

8.2 : Aim

It was the aim of this study to investigate which of the two scales (VAS or VRS) is most appropriate as a pain assessment tool for measuring pain intensity and pain unpleasantness during experimental ischaemic pain induction.

8.3 : Design

A correlational design tested the relationship between the scores obtained from the verbal rating scale (VRS) and the visual analogue scale (VAS) at each one minute interval during pain induction.

8.4 : Methodology

8.4.1 : Materials and instrumentation (photograph in Appendix 8)

* information sheet / consent form (Appendix 7)
* visual analogue scales (VAS) (Appendix 9)
* verbal rating scales (VRS) (Appendix 9)
* hand - held dynamometer (PyMaH Trimline™)
* elastic bandage
* sphygmomanometer cuff (Sylgard™ 125mm wide)
* stopwatch

8.4.2 : Subject Recruitment

Twelve subjects (all female; mean age 19.3 years; range 18-20) were recruited from Queen Margaret College student population by means of poster advertising. The posters outlined the basic nature of the study and were placed on noticeboards throughout the College. Once subjects expressed a willingness to participate in the study, a timetable was agreed upon when the subject would attend the session.

8.4.3 : Ethics

Ethical approval was granted by the College Ethical Committee before commencing the study. Each subject was asked to read an information sheet during their initial attendance. In the information sheet the subject was asked if they were aware of having any of the listed contra-indications to the procedure. These included having any current or a recent history of significant pain in the body, a history of heart complaints, or analgesic substance intake within the 24 hours prior to the study. Positive replies for these questions resulted in elimination from the study. All 12 subjects fulfilled the selection criteria (see Appendix 7) and did not have to be eliminated from the study. Subjects were reminded of their right to withdraw from the study at any time without giving reason. The information sheet outlined the basic procedure and the possible sensations that could be experienced by the pain induction procedure (see Appendix 7). The subjects were then encouraged to ask any necessary questions regarding the information they have been given and asked to sign a consent form (see Appendix 7). The consent form stated the responsibilities of the experimenter under the data protection legislation (Data Protection Act 1984).

8.4.4 : Pain Induction

Subjects were asked which hand they usually write with and this was taken to be the dominant arm. The non-dominant arm was used in each case to standardise conditions. Maximum grip strength was measured in the non-dominant arm using a hand-held dynamometer (the higher of two readings was taken as the result). The non-dominant arm was then elevated for 60 seconds while an elastic bandage was wrapped tightly around the distal two-thirds of its length. The cuff (Sylgard™ 125mm depth) was then applied just above the elbow and inflated as quickly as possible to a pressure of 250mmHg. The bandage was then removed and the arm lowered and rested horizontally on a plinth. Twenty seconds later the subject carried out 20 repetitions of gripping exercises (2 seconds grip / 2 seconds release) at 75% of maximum grip strength. Immediately after the last repetition had been completed the time was taken as zero and the stopwatch started. The maximum time that the cuff remained inflated was 15 minutes although subjects were informed of their right to request deflation before this time had elapsed.

8.4.5 : Pain Assessment

Once the stopwatch had been started the subject was handed 2 sheets of paper, immediately after one another, at one minute intervals until cuff deflation. Each piece of paper contained a visual analogue scale (VAS) and a verbal rating scale (VRS) (see Appendix 9). The first sheet assessed pain intensity, while the second sheet assessed pain unpleasantness. The VAS was comprised of a straight 10cm line but the anchor words differed depending on which dimension of pain the scale was assessing. The pain intensity VAS possessed the anchors "no pain" and "the

worst pain imaginable" while the pain unpleasantness VAS had " not bad at all" and "the most unpleasant sensation imaginable". The VRSs both contained a ranked list of verbal pain descriptors, in each case the words being appropriate for the dimension of pain being assessed. The difference between the two pain dimensions was explained to the subjects and they were instructed how to mark the scales prior to starting the test. It was stressed to the subjects to mark the scales according to how they felt exactly at the time of marking. Previously marked scales were not visible to subjects during the pain induction period in an attempt to prevent subjects marking the scales based on their last mark. Quantitative data from the VAS was obtained by measuring the distance of the vertical line marked by the subject from the left-sided anchor point of the scale to the nearest millimetre (mm) - this measurement was carried out by the experimenter. The responses given in the VRS were quantified by using numerical values previously assigned to the descriptors by a comparable population using cross-modality matching techniques (Duncan et al, 1985).

8.4.6 : Data analysis

The mean score for both scales at each minute interval was calculated and the relationship between the means of the two scales was tested using Pearson's Product Moment Correlations (Winer, Brown and Michels, 1991). The relationship between the scales at each minute interval was computed by the Excel™ software programme using a PC. The coefficient of determination (r^2) was determined at each time point. This figure is an estimate of the degree of similarity of the paired means and measures the proportion of variance in one score which can be

accounted by another (Winer et al, 1991). Correlations were be classed as being high ($r^2>0.81$), moderately high ($r^2>0.64$) moderate ($r^2>0.49$) or low ($r^2<0.49$) (Payton, 1994).

8.5 : Hypotheses

The following hypotheses were tested in experiment 1:

(I) Hypothesis (H_1)

There will be a high / moderately high ($r^2>0.64$) correlation between the VAS and VRS pain intensity scores assessed at minute 1 [1] during the induction of experimental ischaemic pain.

Null Hypothesis (H_o)

There will not be a high / moderately high ($r^2>0.64$) correlation between the VAS and VRS pain intensity scores assessed at minute 1 [2] during the induction of experimental ischaemic pain.

---

[1] The H_1 for VAS and VRS pain intensity scores will be repeated 15 times so that each of the assessment time points can be addressed separately i.e. min 2, min 3 ... min 15.

[2] The H_o for VAS and VRS pain intensity scores will be repeated 15 times so that each of the assessment time points can be addressed separately i.e. min 2, min 3 ... min 15.

(II) Hypothesis (H_2)

There will be a high / moderately high ($r^2>0.64$) correlation between the VAS and VRS pain unpleasantness scores assessed at minute 1 [3] during the induction of experimental ischaemic pain.

Null Hypothesis (H_o)

There will not be a high / moderately high ($r^2>0.64$) correlation between the VAS and VRS pain unpleasantness scores assessed at minute 1 [4] during the induction of experimental ischaemic pain.

8.6 : Results

None of the subjects involved in the study completed the full 15 minutes of the pain induction procedure - the average length of time that the cuff was inflated was 8 minutes (range 2 - 11 minutes).

The graphs and data for experiment 1 are shown either here in the text or in Appendix 1. A graph of the mean pain intensity scores during the pain induction period (Figure I in Appendix 1) showed a general upward trend for both scales, with similar mean scores being reported at minutes 4, 10 and 11. No one scale was scored consistently higher than the other and instead they appeared to fluctuate throughout the test. The graph of the mean unpleasantness scores (Figure II in

---

[3] The H_1 for VAS and VRS pain unpleasantness scores will be repeated 15 times so that each of the assessment time points can be addressed separately i.e. min 2, min 3 ... min 15.

[4] The H_o for VAS and VRS pain unpleasantness scores will be repeated 15 times so that each of the assessment time points can be addressed separately i.e. min 2, min 3 ... min 15.

Appendix 1) showed, as for the mean intensity scores, that the subject groups rated their mean pain unpleasantness higher towards the end of the pain induction period. With the unpleasantness scales, however, the VAS was marked consistently higher than the VRS at each assessment time point. The two scales both showed a slight drop in mean scores at minute 2 and then had a shared peak at minute 8. It was only at minute 10 that both scales appeared to have been given the same score.

The raw scores and descriptive statistics summary for each of the 12 subjects are shown in Tables 1c - 1h in Appendix 1. The Pearson Product Moment Correlations carried out for each set of data collected during pain induction found a high / moderately high correlation (r^2>0.64) between the VAS and VRS mean pain intensity scores at each of the 11 time assessment points during pain induction as shown in Table 1a below.

Table 1a : Pearson's Product Moment Correlation Coefficients (r) and Coefficients of Determination (r^2) for VAS and VRS pain intensity scores at one minute intervals during pain induction period in experiment 1

Time (mins)	1	2	3	4	5	6	7	8	9	10	11
n	12	12	10	10	10	10	9	9	6	6	2
r value	.89	.92	.87	.89	.87	.95	.91	.90	.91	.99	1.00
r^2 value	.79	.85	.76	.79	.76	.90	.83	.81	.83	.98	1.00

Correlations between the mean pain unpleasantness scores during experimental ischaemic pain induction were high / moderately high (r^2>0.64) at each time point except minutes 1 (r^2=0.59), 4 (r^2=0.59), 7 (r^2=0.53) and 8 (r^2=0.50) as shown in Table 1b on the next page.

Table 1b : Pearson's Product Moment Correlation Coefficients (r) and Coefficients of Determination (r^2) for VAS and VRS pain unpleasantness scores at one minute intervals during pain induction period in experiment 1

Time (mins)	1	2	3	4	5	6	7	8	9	10	11
n	12	12	10	10	10	10	9	9	6	6	2
r value	.77	.90	.95	.77	.91	.92	.73	.71	.93	.95	1.00
r^2 value	.59	.81	.90	.59	.83	.85	.53	.50	.86	.90	1.00

All the pain intensity null hypotheses from minutes 1-11 could therefore be rejected, along with the pain unpleasantness null hypotheses for minutes 2,3,5,6,9,10 and 11. The hypotheses (intensity and unpleasantness) from minutes 12-15 could be ignored as no subjects tolerated that length of ischaemic pain induction. The statistical results supported the graphical data that the two scales showed a high / moderately high correlation. This indicated that the scales were related in the present experiment.

8.7 : Discussion

The aim of the study was to compare the suitability of the two scales for measuring pain intensity and pain unpleasantness during experimental ischaemic pain. The Pearson Product Moment Correlation was calculated at each time assessment point (1 minute intervals) during the pain induction period and the range of corresponding coefficients of determination for the intensity and unpleasantness scores were found to be (intensity r^2=0.76-1.00) and (unpleasantness r^2=0.50-1.00) respectively. The results showed that there was a high correlation between the VAS and VRS at the majority of time assessment points but that, regarding the pain

unpleasantness component, there were periodic discrepancies between the two assessment tools.

The discrepancy between the two pain unpleasantness scales at the identified time points may have been attributable to the features of the scales. The VAS consisted of a line that had, theoretically, an indefinite number of response categories. The VRS, on the other hand, possessed only 9 different choices for rating pain unpleasantness. In practice, therefore, a subject was able to rate pain unpleasantness on a continuum at each consecutive time point on the VAS while on the VRS only a relatively large change in pain perception would have registered as a change in response category.

In order for the VRS to have interval/ratio scaling properties the procedure of cross-modality matching was employed (see Section 7.2.2). The scores used to quantify the two VRS scales were obtained from a comparable experimental population (Duncan et al, 1985) and this was considered to be an appropriate time-saving procedure (Duncan et al, 1989; Gracely et al, 1978). The original scoring of the scale, however, was done using French translations of the descriptors which might not be similar when translated back into the English language. The high correlation found by Duncan et al (1989) in a later experiment may have been due to the fact that the subjects were using the French adaptation of the scale or that the scale was suitable for use with experimental heat pain. It appears that the VRS categories in the chosen scales may not always have been sensitive to changes in perceived pain during ischaemic pain induction and this may have been due to them

not being specific to the subjects and experimental pain model being employed in the present study.

Both the VAS and VRS have qualities that make them a suitable tool for assessing pain intensity and pain unpleasantness during ischaemic pain induction (see Sections 7.2.1-7.2.3) but in order for the VRS to have interval / ratio scaling properties cross-modality matching must be carried out. The procedure is extremely time consuming and would involve devising scales that were specific to the ischaemic pain tourniquet test. The results of this experiment supported the view that either scale would be appropriate for assessing pain intensity and pain unpleasantness during ischaemic pain induction and in future studies the VAS will be used exclusively as the assessment tool. The aim of the next study was to identify variables within the pain induction procedure which cause an increase in pain perception and manipulate the methodology so that fewer subjects drop-out before the full 15 minutes of pain induction has been completed.

8.8 : Conclusions

(1) The VAS and VRS used in the present experiment were found to produce similar pain measures (intensity and unpleasantness) during pain induction.

(2) The VAS will be used alone in successive studies due to the time required to match cross-modality scores to a VRS specific to the study.

Chapter 9 : Experiment 2 - Investigation of the effect of cuff pressure on VAS scores measuring pain intensity and pain unpleasantness using the ischaemic pain tourniquet test on healthy female volunteers.

9.1 : Introduction

An issue raised by experiment 1 was the methodology of the pain induction procedure, with subjects only tolerating the test for an average of 8 minutes. The literature (see Section 6.4.6 and 6.5) referred to experimenters using between 7 and 25 minutes duration of the ischaemic pain tourniquet test and no significant numbers of drop-outs of the test were reported before the full time had elapsed.

A paper published by Pertovaara et al (1984) suggested that both cuff pressure and exercise intensity have an effect on pain scores and tolerance time for the ischaemic pain tourniquet test. Smith et al (1966) who first standardised a test of ischaemia of a limb with contraction of the ischaemic muscles used a cuff pressure

of 250mmHg and carried out 20 gripping exercises (2 seconds grip / 2 seconds release) of a hand spring at a pre-determined tension (tension not stated). Experimenters using this model of experimental pain have since commonly used cuff pressures of either 200mmHg (Walsh et al, 1995; McDowell, Lowe, Walsh, Baxter and Allen, 1995) or 250mmHg (Woolf, 1979; Roche et al, 1984; Posner, 1984). The variable of exercise intensity has been slightly more varied, with some experimenters selecting a set tension, for example, 2.5kg (Woolf, 1979) while others used a percentage of the subject's maximum grip strength ranging from 25% (Roche et al, 1984) to 75% (Foster et al, 1995; Walsh et al, 1995). A large number of the ischaemic pain studies have selected 20 as the number of exercise repetitions (Woolf, 1979; Roche et al, 1984; Foster et al, 1995, Walsh et al, 1995) but the time taken to carry out these exercises has not been consistent across methodologies. Foster et al (1995) and Walsh et al (1995) suggested 1 minute for carrying out the exercises while others were more specific and gave actual grip and release times for the exercises; 1 second grip (McDowell et al, 1995) or 2 seconds grip / 2 seconds release (Smith et al, 1966; Roche et al, 1984). From reviewing a range of methodologies used with the experimental ischaemic pain model it is clear to see that no one set of variables has been consistently selected.

Pertovaara et al (1984) stated that cuff pressure and exercise intensity were responsible for different types of pain (pain caused by direct pressure of the cuff on the arm and pain distal to the cuff caused by the build-up of metabolites, respectively). This opinion reflected that of Procacci et al (1979) who proposed that pain was multifactorial and contained both a metabolic and neurological

component. Nathan (1953, in Procacci et al, 1979) was reported to have observed that pressure-induced ischaemia of a nerve produced an increase in pain fibre excitability. This allowed previously subliminal pain stimuli in the region of the affected nerve to reach a threshold level. These findings suggest that it is the variable of cuff pressure that ultimately determines the amount of exercise-induced pain felt during the ischaemic pain tourniquet test. The study by Pertovaara et al (1984) showed that subjects could distinguish between cuff and arm pain and found that higher intensities of exercise increased the ratings given for arm pain. It could be, however, that arm pain is secondary, and dependent on, the amount of pressure produced by the cuff.

The variable of cuff pressure was therefore the primary focus of this study, with the two most commonly used cuff pressures of 200mmHg and 250mmHg being compared. Exercise intensity was kept constant throughout the study, using 20 gripping exercises at 75% of maximum grip strength (1 second grip / 1 second release). These variables of exercise intensity were selected as they are within the range most commonly used in this experimental model of pain. Experiment 1 identified the need for a more structured method of recording subjective reportings of the ischaemic pain test. In light of the findings by Pertovaara et al (1984), a questionnaire was designed for use in this study to ask subjects, among other questions, if two separate types of pain had been identified during the test (see Appendix 11).

It was noted during the pain induction procedure in Experiment 1 that some of the subjects expressed a concern as to the change in appearance of the affected arm due to the blood occlusion. During this study, therefore, the non-dominant arm was covered with a blanket to minimise the subjects' anxiety.

9.2 : Aim

The aim of the present study was to compare two cuff pressures (200mmHg and 250mmHg) used in the ischaemic pain induction procedure to investigate their influence on the degree of pain reported.

9.3 : Design

An experimental design with 2 factors was used in this study. There were repeated measures on both factors, with the first factor of cuff pressure containing two levels (200mmHg and 250mmHg). The second factor was time and consisted of 15 levels representing pain assessment times spaced equally one minute apart. A cross-over design was incorporated into the study with half the subjects receiving the 200mmHg cuff pressure first while the other half received the 250mmHg cuff pressure during the initial testing session. All subjects received both cuff pressures and there were approximately 48 hours between testing sessions.

9.4 : Methodology

9.4.1 : Materials and instrumentation (photograph in Appendix 8)

The same materials and instrumentation were used in the present study as was used in experiment 1 except for the following items:

* blanket

* visual analogue scales (VAS) (Appendix 10)

* questionnaire (Appendix 11)

9.4.2 : Subject Recruitment

The same recruitment procedure was used as in experiment 1. Eight subjects were recruited from Queen Margaret College student population (all female; age range 21-31 years; mean age 24.25 years).

9.4.3 : Ethics

Ethical approval was granted by the College Ethical Committee before commencing the study. The same information / consent form (Appendix 7) was used as in experiment 1. All subjects fulfilled the selection criteria and no one had to be eliminated from the study.

9.4.4 : Pain Induction

The same pain induction procedure was used as in experiment 1 except that the cuff (Sylgard™ 125mm depth) was inflated to a pressure of either 200mmHg or 250mmHg, as appropriate. The mercury pressure recorder was turned to face away from the subject throughout the experimental procedure so that the subject

was unaware of what pressure the cuff had been inflated to. The other difference between the pain induction procedure for this experiment and that used in experiment 1 was that the timing of the 20 gripping exercises (75% of maximum grip strength) was reduced from 2 seconds grip / 2 seconds release to 1 second grip / 1 second release. Also, the affected limb was covered with a blanket throughout the test to minimise anxiety which could arise due to changes in the arm's appearance.

9.4.5 : Pain Assessment

The same pain assessment procedure was used as in experiment 1 except that only the VAS was used to measure both pain intensity and pain unpleasantness. Each sheet was identical, containing a pain intensity VAS and a pain unpleasantness VAS (Appendix 10). Each scale consisted of a straight 10cm line, with different anchor words depending on which dimension of pain the scale was assessing. The pain intensity VAS possessed the anchors "no sensation" and "the most intense sensation imaginable" while the pain unpleasantness VAS had "not bad at all" and "the most unpleasant sensation imaginable" (Price and Harkins, 1992). Prior to starting the test the difference between the two pain dimensions was explained to the subjects and they were instructed how to mark the scales. The distinction between the 2 dimensions of pain, as in experiment 1, was explained using the analogy of Price et al (1993) and it was stressed to the subjects to mark the scales according to how they felt exactly at the time of marking. The orientation of each scale was different on each sheet of paper (intensity VAS - horizontal; unpleasantness VAS - vertical) to highlight the difference between the two

different components of pain being assessed. The minimum anchor was placed at the left hand side of the horizontal VAS and at the top of the vertical VAS. Previously marked scales were not visible to the subjects during the pain induction period in an attempt to prevent subjects marking the scales based on their last mark. Quantitative data from the VAS was obtained by measuring the distance of the vertical line marked by the subject from the left-sided anchor point of the scale to the nearest millimetre (mm) - this measurement was carried out by the experimenter.

9.4.6 : Data analysis

Homogeneity of variance was assessed with the Hartley test (Winer et al, 1991) by manually calculating the ratio of the minimum and maximum variances. The Shapiro-Wilk test of normality of data in small groups was then computed using the SPSS™ computer package to test for deviation from normal distribution. Overall differences among means were investigated by a two way (2x15) analysis of variance (ANOVA) with repeated measures on both factors (Winer et al, 1991) using the SPSS™ computer package. Any interaction effects were investigated manually by analysis of simple main effects with differences between specific means being analysed, also manually, by the post-hoc Scheffe test (Philips, 1978). In all cases statistical significance was accepted at the $p \leq 0.05$ level.

9.5 : Hypotheses

The following hypotheses were tested in experiment 2:

(I) Hypothesis (H_1)

There will be a statistically significant difference between mean VAS pain intensity scores during the ischaemic pain tourniquet test dependent on whether a cuff pressure of 200mmHg or 250mmHg is used.

Null Hypothesis (H_o)

There will be no statistically significant difference between mean VAS pain intensity scores during the ischaemic pain tourniquet test dependent on whether a cuff pressure of 200mmHg or 250mmHg is used.

(II) Hypothesis (H_2)

There will be a statistically significant difference between mean VAS pain unpleasantness scores during the ischaemic pain tourniquet test dependent on whether a cuff pressure of 200mmHg or 250mmHg is used.

Null Hypothesis (H_o)

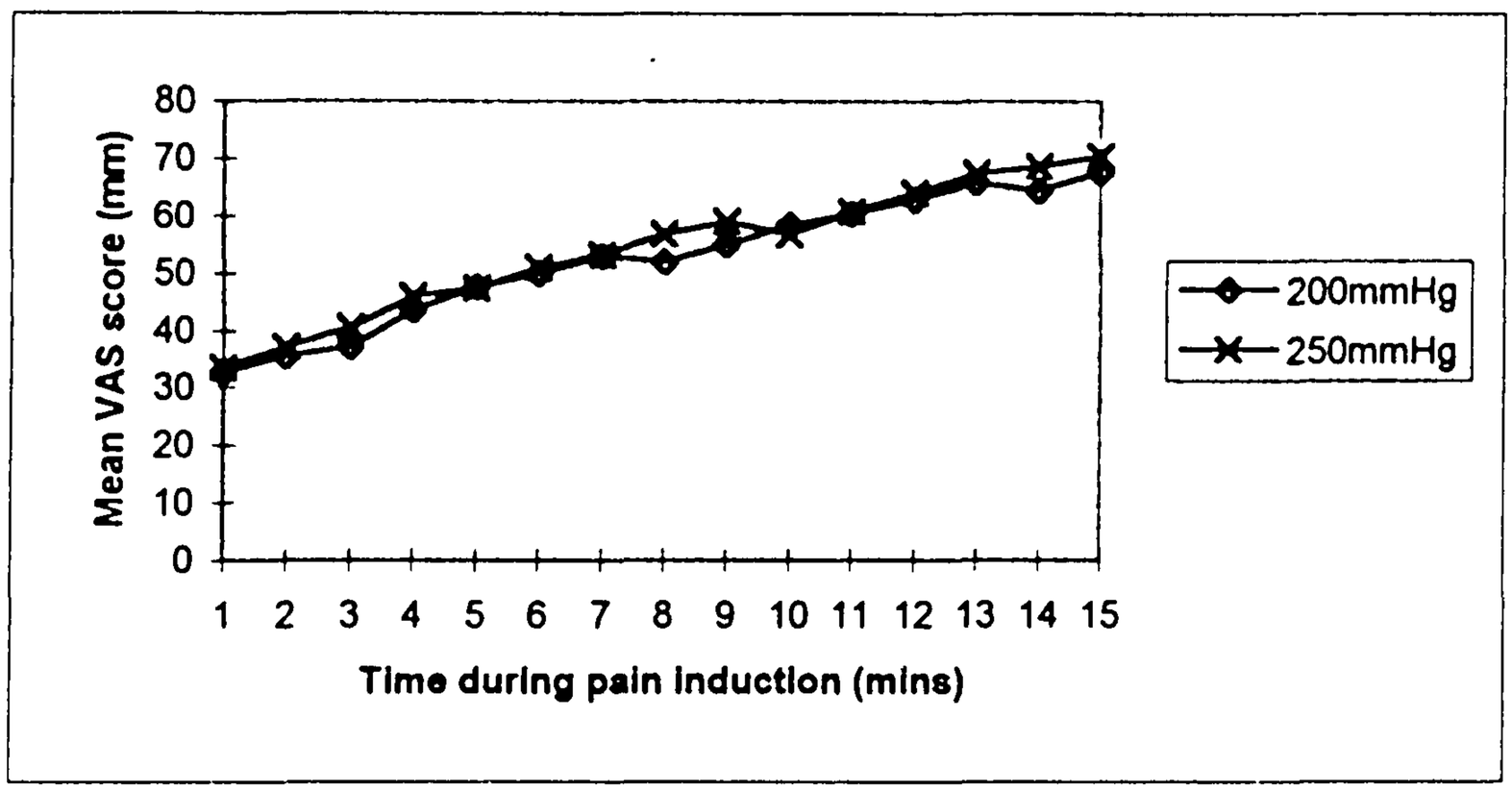
There will be no statistically significant difference between mean VAS pain unpleasantness scores during the ischaemic pain tourniquet test dependent on whether a cuff pressure of 200mmHg or 250mmHg is used.

9.6 : Results

One of the subjects did not complete the full 15 minutes of the pain induction procedure and was therefore not included in the statistical analysis of the results. There were no other drop-outs from the study.

Graphs and tables of the data are shown either here in the text or in Appendix 2. A graph of the mean pain intensity scores at both cuff pressures is shown below in Figure V.

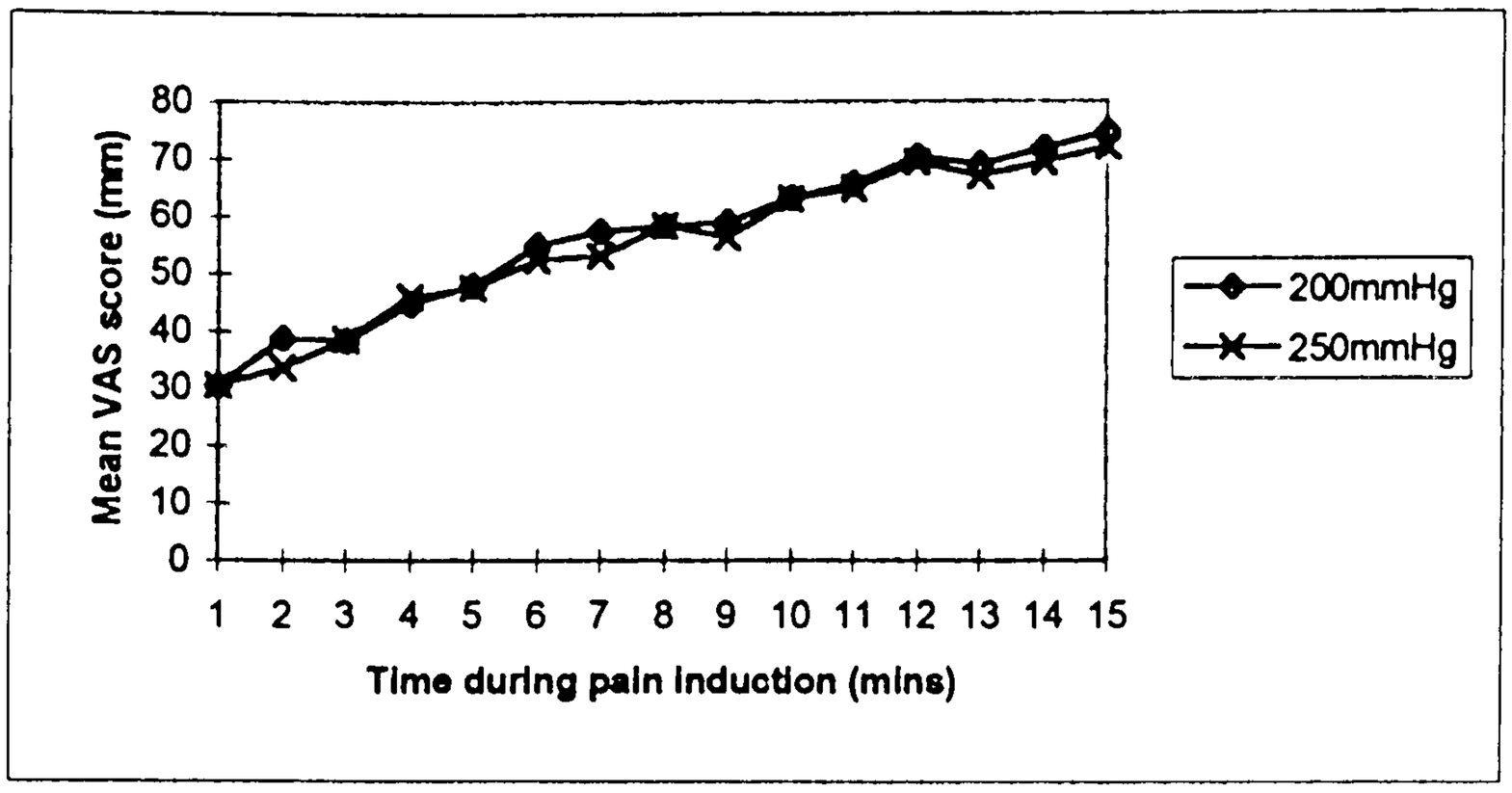
Figure V : Mean VAS pain intensity scores at both cuff pressures (200mmHg and 250mmHg)



Subject groups showed a general upward trend in mean pain intensity rating throughout the pain induction period but no one cuff pressure produced noticeably higher mean pain intensity scores.

Mean pain unpleasantness scores at the two cuff pressures are also shown in Figure VI on the next page and again both followed a very similar upward trend throughout the test.

Figure VI : Mean VAS pain unpleasantness scores at both cuff pressures



The raw scores for all subjects, including the descriptive statistics, are shown in tables 2c (intensity) and 2d (unpleasantness) in Appendix 2. Only pain intensity measurements at minute 7 using the 250mmHg cuff pressure and pain unpleasantness measurements at minute 1 using the 200mmHg cuff pressure showed a statistically significant deviation from normal distribution ($p<0.05$). The assumption of homogeneity of variance, measured by the Hartley test, was rejected (intensity $F=5.17$; d.f.=30,6; $p>0.05$; unpleasantness $F=4.00$; d.f.=30,6; $p>0.05$).

Overall differences between the means of the two cuff pressures were investigated by a two way (2x15) analysis of variance (ANOVA) with repeated measures on both factors (Tables 2a and 2b shown on the next page). The ANOVA of the pain scores showed no statistically significant effect of cuff pressure on either VAS pain intensity measures ($F=0.09$; d.f.=1,6; $p=0.771$) or VAS pain unpleasantness measures ($F=0.04$; d.f.=1,6; $p=0.851$). The effect of time was found to be significant on VAS intensity scores for both pain measures (intensity $F=17.53$;

d.f.=14,84; p<0.001; unpleasantness F=17.79; d.f.=14,84; p<0.001) but there was no significant interaction effect of cuff pressure over time (intensity F=0.22; d.f.=14,84; p=0.999; unpleasantness F=0.15; d.f.=14,84; p=1.00).

Table 2a : ANOVA table for experiment 2 pain intensity scores

VAS INTENSITY	SS	d.f.	MS	F	p
Effect of Cuff					
Cuff	162.98	1	162.98	0.09	0.771
Error (Within + Residual)	10581.79	6	1763.63		
Effect of Time					
Time	25274.70	14	1805.34	17.53	<0.001
Error (Within + Residual)	8651.44	84	102.99		
Interaction (Cuff x Time)					
Cuff x Time	163.67	14	11.69	0.22	0.999
Error (Within + Residual)	4512.07	84	53.72		

Table 2b : ANOVA table for experiment 2 pain unpleasantness scores

VAS UNPLEASANTNESS	SS	d.f.	MS	F	p
Effect of Cuff					
Cuff	112.93	1	112.93	0.04	0.851
Error (Within + Residual)	17645.60	6	2940.93		
Effect of Time					
Time	35248.55	14	2517.75	17.79	<0.001
Error (Within + Residual)	11884.98	84	141.49		
Interaction (Cuff x Time)					
Cuff x Time	148.21	14	10.59	0.15	1.000
Error (Within + Residual)	6094.26	84	72.55		

Results of the questionnaire are summarised in Table 2e in Appendix 2. With the exception of one subject, all tolerated 15 minutes of pain induction. All the subjects in the study reported that they were able to distinguish between pain

intensity and pain unpleasantness and marked the VAS appropriately. At the higher cuff pressure all the subjects distinguished between the cuff and arm pain while only 5 reported noticing a difference at the lower cuff pressure. Of those who distinguished between the pains, the numbers were equally divided as to which pain was worse (4 reported arm, 4 reported cuff) at the higher cuff pressure. At the lower cuff pressure 3 reported that the arm pain was perceived as being more painful while 2 reported that it was the cuff pain.

9.7 : Discussion

The results of this study showed that, using the selected pain induction methodology, 200mmHg and 250mmHg cuff pressures produced mean VAS pain intensity and mean VAS pain unpleasantness scores that were not statistically significantly different from each other. The significant F ratio for the time factor (in each case $p<0.001$) and visual examination of the data showed that the subjects found the pain induction procedure progressively more intense and unpleasant the longer the cuff was inflated. This finding supported the idea that the submaximal tourniquet method is an effective model of experimental pain induction. The differences between pain scores dependent on cuff pressure, however, were not significant and neither null hypothesis could be rejected. The findings indicated that if the same pain induction procedure were followed in future experiments, the pain scores obtained (intensity and unpleasantness) would be similar regardless of whether a cuff pressure of 200mmHg or 250mmHg were selected.

It is possible that the heterogeneity of variances found with both the intensity and unpleasantness scores (Hartley test) may have compromised the statistical power of the ANOVA. This is unlikely, however, as the equal numbers in each group make it robust against departures from the assumptions about parametric requirements of normal distribution of data and permit it to be a valid statistical test (Winer et al, 1991).

It was proposed before the study, based on reported observations by Nathan (1953, in Procacci et al, 1979), that cuff pressure was most likely to be the primary determinant of pain ratings and pain tolerance during the ischaemic pain tourniquet test. The author was reported to have found that once pressure-induced ischaemia had been produced, pain in the affected limb became greater due to increased excitability of the pain fibres. Pertovaara et al (1984) proposed that two types of pain occur in the ischaemic model of pain induction and that these were due to (1) nerve pressure caused by the cuff and (2) accumulation of metabolites caused by exercise of ischaemic muscles. The findings of Nathan (1953, in Procacci et al, 1979) and Pertovaara et al (1984) suggested that exercise-induced pain due to metabolite build-up may be secondary and dependent on the cuff pressure used.

All subjects, except one, participating in the present experiment tolerated the full 15 minutes of pain induction at cuff pressure 250mmHg while in experiment 1 the average time endured was only 8 minutes (the cuff pressure was also 250mmHg). Exercise intensity in the present experiment (2s grip / 2s release) was less than that carried out in experiment 1 (1s grip / 1s release) which would, theoretically, have

reduced the amount of arm pain experienced by the subjects. It has been proposed that arm pain could be dependent on cuff pressure and, therefore, in experiment 1, the cuff pressure had the effect of increasing the arm pain to the extent that pain tolerance was reduced. It would also follow that the reduction of exercise intensity in the present study could consequently have reduced arm pain to produce a level of pain which allowed the full 15 minutes of pain induction to be tolerated.

The results of the questionnaire supported the theory that perception of arm pain is dependent on cuff pressure as all of the 8 subjects reported noticing a difference in cuff and arm pain at the higher cuff pressure, while only 5 reported noticing the distinction when the lower cuff pressure was used. The questionnaire responses showed, however, that the arm pain was not always perceived as being more painful than the pain produced by the cuff. It could be that the higher cuff pressure allows the distinction between the two types of pain to be made but does not allow for a clear distinction to be made as to which pain is worse. This is reflected in the result that the numbers of subjects who reported that one type of pain (arm or cuff) was worse than the other were almost equally split at both cuff pressures.

An important point of note in the questionnaire responses can be observed in the 'extra info' column (Table 2e). Subject number 7 commented that they had not found the pain induction procedure using the 250mmHg cuff pressure to be painful but instead it had produced a 'strange' sensation. At the higher cuff pressure (250mmHg), another subject (number 6) reported a feeling of 'discomfort' as opposed to pain. Comments of this type were not made by all the subjects

participating in the experiment but the analysis of the VAS scores showed that the higher cuff pressure (250mmHg) did not produce sensations that were perceived as being more painfully intense or unpleasant than the lower (200mmHg) cuff pressure. The responses of the questionnaire in the present experiment indicated that the higher cuff pressure (250mmHg) did allow a greater number of subjects to distinguish between cuff and arm pain but did not allow one to be perceived as being more painful than the other. Cuff pressure in the present experiment, therefore, was found to influence the subjective reporting of sensations produced by the ischaemic pain induction but these sensations were not perceived as being painful (intensity or unpleasantness). A cuff pressure of 200mmHg was therefore used in future experiments.

Subjects in the study were tested twice and the time between testing sessions was taken to be 48 hours based on previous ischaemic pain studies (Foster et al, 1995; McDowell et al, 1995; Walsh et al, 1995) and time-tabling considerations. This study used a cross-over design and therefore any carry-over effects of the test would have been minimised. For future studies of a repeated measures design, however, the repeatability of the test over the selected time period was investigated.

9.9 : Conclusions

(1) Analysis of the VAS scores in the present experiment indicated that subjects did not perceive one cuff pressures to be more painful (intensity or unpleasantness) than the other.

(2) The questionnaire responses in the present experiment indicated that the higher cuff pressure (250mmHg) did produce different subjective reportings of sensation from the lower cuff pressure (200mmHg) but that these sensations were not perceived as being painful.

Chapter 10 : Experiment 3 - Investigation of pain scores during pain induction when healthy female volunteers are subjected to repeated exposure to the ischaemic pain tourniquet test.

10.1 : Introduction

The ischaemic tourniquet test is an established model of experimental pain (see Sections 6.4.6 and 6.5) but little literature has been published regarding its repeatability. Studies using repeated tests of the ischaemic model of experimental pain have used gaps between successive tests ranging from 48 hours (Foster et al, 1995; McDowell et al, 1995; Walsh et al, 1995) to periods of up to 1 week (Woolf, 1979) and 3 weeks (Pertovaara et al, 1984). None of these experimenters stated why they chose their selected time period and only Pertovaara et al (1984) made reference to the repeatability of the pain model. Pertovaara et al (1984) exposed 12 subjects to a total of 4 tests, 2 of which were identical in procedure (1st and 4th test). The time gap between testing was reported to have been

between 1 and 3 weeks although the actual number of days was not stated. VAS scores of ischaemic pain intensity and pressure pain intensity (from cuff) were marked by the subjects at 2 minute intervals during the 15 minutes of pain induction. Graphical representation of the results showed that a similar trend in pain reporting was found between the 2 identical tests although the pain scores in the 2nd exposure to the test were slightly lower than in the initial testing session. The authors concluded that the similarity of the 2 successive sets of VAS scores indicated that the ischaemic pain tourniquet test was reliable over repeated sessions. The graph displayed in the paper by Pertovaara et al (1984) was only able to show similarities between mean scores and, as there was no statistical analysis of these results to identify any statistically significant differences, this conclusion cannot be firmly established.

Literature regarding the mechanism of experimental ischaemic pain induction (see Section 6.4.6) suggested that the pain experienced was due to a build-up of metabolites in the affected limb in combination with pain produced by cuff pressure (Lewis, 1950, in Procacci et al, 1979; Pertovaara et al, 1984). It would therefore follow that pain perception would return to pre-test levels shortly after the cuff has been deflated and equilibrium in the tissues has been restored. Lewis (1942, in Keele and Neil, 1965) was reported as noting that once circulation is restored, a time period of 2-4 seconds allows pain to return to pre-test levels. This report is in agreement with subjective statements made in the 2 earlier experiments. For this reason, and for time-tabling considerations, a period of 48 hours between tests will be used. It is important to note that using a repeated test

in a repeated measures experimental design can cause major threats to the internal validity of the study (Payton, 1994). Threats to internal validity not only arise due to physiological carry-over effects but are also due to learning effects and increased familiarity with the equipment and procedure. This in turn can produce a change in outcome measures not associated with a change in the variable being assessed.

10.2 : Aim

The aim of the experiment was to investigate if the present experimental model of pain produced a repeatable measure of pain perception (intensity and unpleasantness) when subjects were exposed to 3 experimental testing sessions 48 hours apart.

10.3 : Design

An experimental design with 2 factors was used in this study. There were repeated measures on both factors, with the first factor of testing session containing three levels (1st, 2nd and 3rd test). The second factor was time and consisted of 15 levels representing pain assessment times spaced equally one minute apart. All subjects were tested 3 times, with the identical procedure being followed each time.

10.4 : Methodology

10.4.1 : Materials and instrumentation (photograph in Appendix 8)

The same materials and instrumentation were used as in experiment 2 except there was no questionnaire.

10.4.2 : Subject Recruitment

The same procedure was used as in previous experiments. Six female subjects aged 22-32 years (mean age 25.33 years) were recruited for the study.

10.4.3 : Ethics

Ethical approval was granted by the Queen Margaret College Ethical Committee before commencing the study. The same information sheet and consent form (with the appropriate timetable alterations) were used as in previous experiments. No subjects had to be eliminated from the study.

10.4.4 : Pain Induction

The same pain induction procedure was used as in experiment 2 except a cuff pressure of 200mmHg was maintained throughout the study.

10.4.5 : Pain Assessment

The same pain assessment procedure was used as in experiment 2 except there was no questionnaire at the end of the final testing session.

10.4.6 : Data analysis

The same statistical tests were carried out as in experiment 2. Overall differences among means were investigated by a two way (3x15) analysis of variance (ANOVA) with repeated measures on both factors (Winer et al, 1991). The 2 factors were order of test (1st, 2nd or 3rd) and time (1 minute intervals x 15).

10.5 : Hypotheses

The following hypotheses were tested in experiment 3:

(I) Hypothesis (H_1)

VAS pain intensity scores will be statistically significantly different between 3 different sessions of the ischaemic pain tourniquet test.

Null Hypothesis (H_O)

VAS pain intensity scores will not be statistically significantly different between 3 different sessions of the ischaemic pain tourniquet test.

(II) Hypothesis (H_2)

VAS pain unpleasantness scores will be statistically significantly different between 3 different sessions of the ischaemic pain tourniquet test.

Null Hypothesis (H_O)

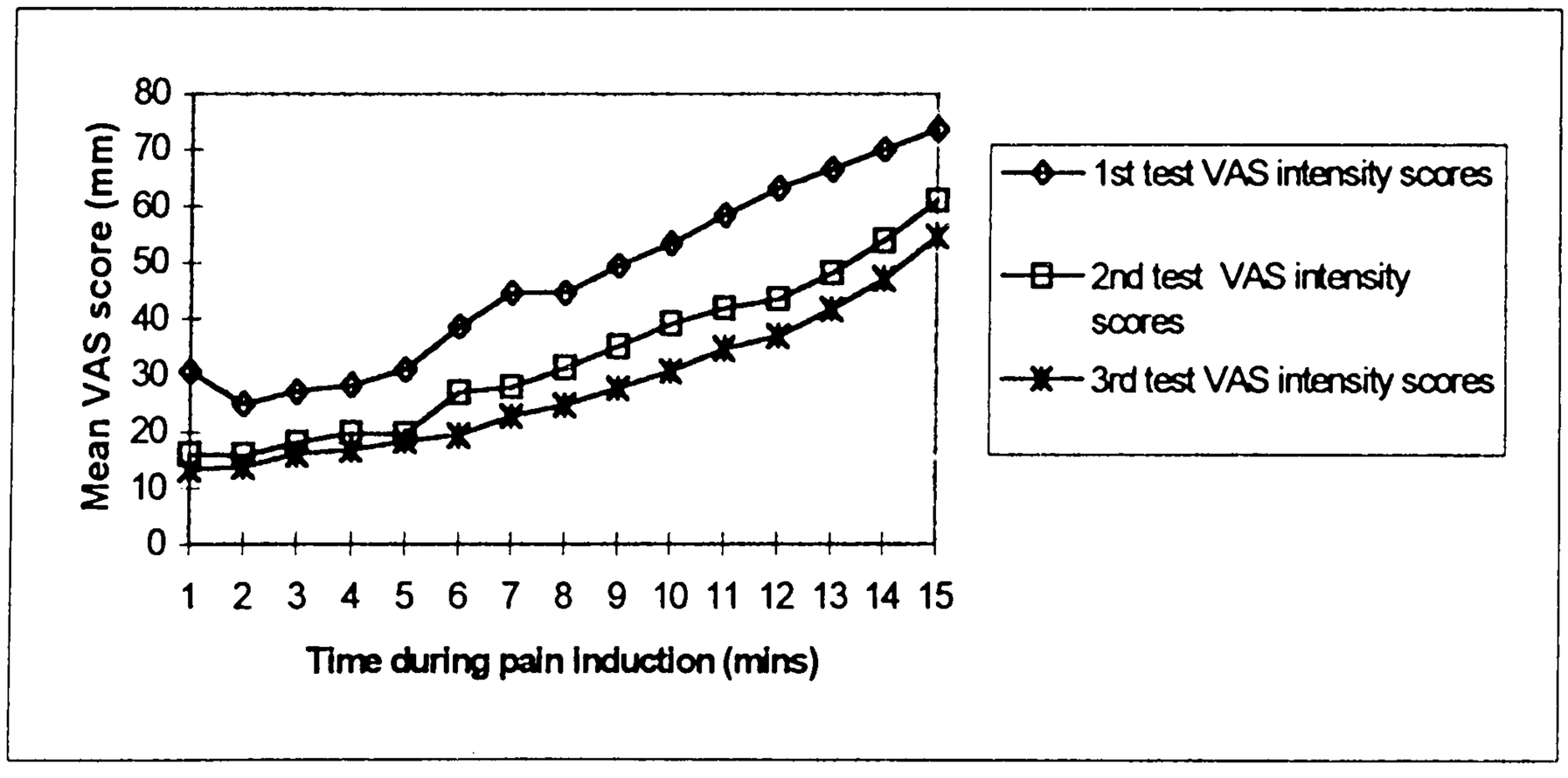
VAS pain unpleasantness scores will not be statistically significantly different between 3 different sessions of the ischaemic pain tourniquet test.

10.6 : Results

One subject did not complete the full 15 minutes of the pain induction procedure and was therefore not included in the analysis of the results. The number of subjects involved in the statistical analysis of the results was 5.

Graphs and tables of the data in experiment 3 are shown either here in the text or in Appendix 3. The Hartley test, carried out manually, showed that assumption of homogeneity of variance was unlikely for either the intensity ($F=35.01$; d.f.=45,4; $p>0.05$) or unpleasantness scores ($F=19.28$; d.f.=45,4; $p>0.05$). A graph of the mean VAS pain intensity scores over all 3 testing sessions is shown in Figure VII below.

Figure VII : Mean VAS pain intensity scores over all 3 testing sessions

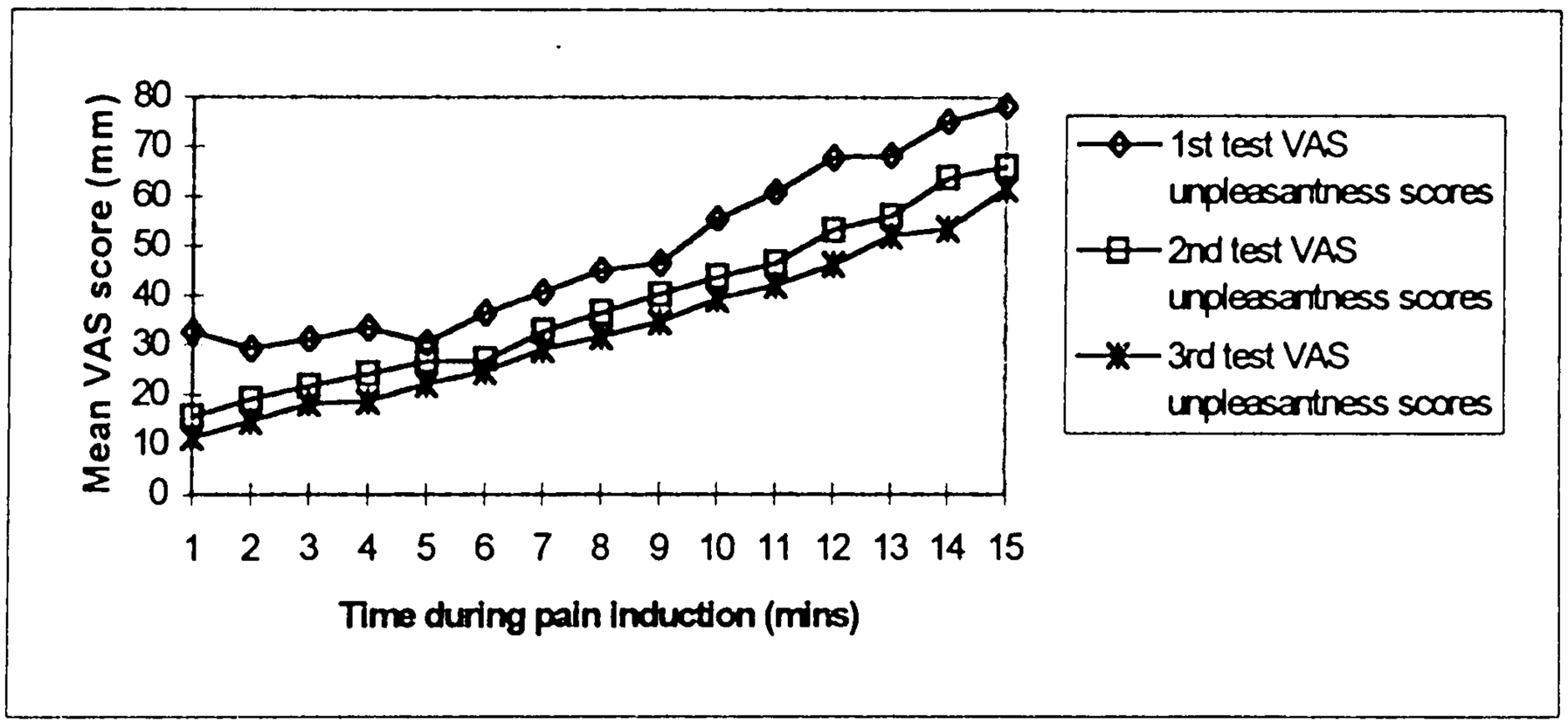


The graph showed a general upward trend in mean VAS pain intensity scores over time throughout the period of pain induction for all 3 tests but the scores for test 1 were higher than those for either of the later tests which showed similar results. The mean pain intensity score in the 1st test was also higher at minute 1

than at minute 2 which was uncharacteristic of the 2nd or 3rd test. This relative high scoring of pain intensity in the initial stages of the 1st test was reflected in the raw data (Tables 3e and 3f) and the graphs of the individual pain intensity scores of all 5 subjects are shown in Figures IX(i)-(iii) in Appendix 3. It can be seen from these 3 graphs that in the 1st test subjects gave a VAS pain intensity score of between 20 and 40 which dropped to below 20 in tests 2 and 3.

Figure VIII below showed the VAS pain unpleasantness scores during pain induction for all 3 testing sessions.

Figure VIII : Mean VAS pain unpleasantness scores over all 3 testing sessions



As with the mean pain intensity scores, the scoring of mean pain unpleasantness in all of the tests followed a similar upward trend but generally decreased the more times that the subjects were exposed to the procedure. The graphs of the individual scores for all 5 subjects over the 3 tests are shown in Figures X(i)-(iii) in Appendix 3. Figure X(i) explains why, as for the VAS mean pain intensity scores, there was a relatively high mean pain unpleasantness score at minute 1 in

the 1st test. Subject 1 gave a pain unpleasantness score of 89 which quite dramatically increased the mean score for that particular time assessment point. Subject number 2, on the other hand, gave a lower than average pain unpleasantness rating at the same time point but this appears to have been reflective of this particular subject's pain reporting in general.

A two way (3x15) analysis of variance (ANOVA) with repeated measures on both factors was carried out on the VAS pain intensity scores. The ANOVA (Table 3a shown below) showed a statistically significant difference between the 3 testing sessions in the study ($F=12.21$; d.f.=2,8; $p=0.004$). There was no statistically significant interaction effect ($F=0.98$; d.f.=28,112; $p=0.505$) indicating that there was no statistically significant difference between the conditions that was dependent on time.

Table 3a : ANOVA table for experiment 3 VAS pain intensity scores

VAS INTENSITY	SS	d.f.	MS	F	p
Effect of Test					
Test	14537.21	2	7268.60	12.21	0.004
Error (Within + Residual)	4761.77	8	595.22		
Effect of Time					
Time	44273.82	14	3162.42	16.88	<0.001
Error (Within + Residual)	10491.69	56	187.35		
Interaction (Test x Time)					
Test x Time	1051.32	28	37.55	0.98	0.505
Error (Within + Residual)	4299.03	112	38.38		

A test of simple main effects was carried out manually on the VAS pain intensity scores to establish at which time points the pain scores were statistically significantly different from each other (Table 3d). Post-hoc Scheffe tests were

then performed to identify where the statistically significant differences could be found between the 3 testing sessions (Table 3b shown below).

Table 3b : Scheffe Test for VAS pain intensity scores in experiment 3

Time	1st test / 2nd test (F)	1st test / 3rd test (F)	2nd test / 3rd test (F)
Minute 1	4.77	7.12*	0.23
Minute 5	0.30	3.10	1.47
Minute 6	1.33	13.26*	6.19*
Minute 7	4.51	16.54*	4.14
Minute 8	1.00	11.75*	5.89
Minute 9	1.33	15.10*	7.46*
Minute 10	1.55	18.57*	9.39*
Minute 11	0.88	14.62*	8.32*
Minute 12	10.47*	15.57*	0.50
Minute 13	11.22*	15.18*	0.30
Minute 14	9.70*	13.49*	0.52
Minute 15	5.43	5.12	0.004

Critical Value = 6.14-8.92

* = statistically significant ($p \leq 0.05$)

The tests showed that the mean VAS pain intensity scores were statistically significantly lower in the 3rd test compared to the 1st test at the majority of the pain assessment time points. Differences which reached statistical significance could also be seen in the earlier and middle stages of the test (minutes 6, 9, 10 and 11) between the 2nd test and the 3rd test and between the 1st test and 2nd test at minutes 12, 13 and 14.

Regarding the statistical analysis of the VAS pain unpleasantness scores, the ANOVA (Table 3c shown on the next page) showed no statistically significant difference between the conditions ($F=2.48$; d.f.=2,8; $p=0.146$). This was also the case with the interaction effect ($F=1.30$; d.f.=28,112; $p=0.172$) and means that there was no statistically significant difference between treatment conditions that was dependent on time.

Table 3c : ANOVA table for experiment 3 VAS pain unpleasantness scores

VAS UNPLEASANTNESS	SS	d.f.	MS	F	p
Effect of Test					
Test	9495.90	2	4747.95	2.48	0.146
Error (Within + Residual)	15345.30	8	1918.16		
Effect of Time					
Time	55794.62	14	3985.33	14.97	<0.001
Error (Within + Residual)	14910.98	56	266.27		
Interaction (Test x Time)					
Test x Time	731.70	28	26.13	1.30	0.172
Error (Within + Residual)	2257.10	112	20.15		

10.7 : Discussion

The results of this experiment showed a statistically significant difference in VAS pain intensity scores between 3 different sessions of the ischaemic pain tourniquet test. The descriptive statistics (Table 3e in Appendix 3) for the intensity scores showed that the standard deviations and variation for each testing session became less as the test order increased and indicated that the subjects were less erratic in their pain rating the more times they were exposed to the test. This was also reflected in the outcomes of the Shapiro-Wilk test as only one value (minute 2) deviated from a normal distribution in the 3rd test while 3 values deviated in the 1st (minutes 13,14 and 15) and 2nd test (minutes 6, 12 and 13). A similar trend could be seen with the VAS pain unpleasantness scores (Table 3f in Appendix 3) although the standard deviations and variations were generally higher than with the intensity scores. This could be due to unpleasantness, based on neurophysiological evidence of specific pain pathways, being open more to modulation (Fields, 1987; Guilbaud et al, 1994; Jones, 1997; Lima, 1997). The sensory-discriminative component of pain (pain intensity) is neurophysiologically

well defined as it is served by the lateral ascending pathways which have few synaptic junction and have discrete target sites (Lima, 1997). This is not the case with the motivational-affective component of pain as it is served by the multi-synaptic medial ascending systems which have diffuse supraspinal target sites (Jones, 1997; Lima, 1997). The motivational-affective component of pain is thought to be influenced by an individual's subjective interpretation of the stimulus and the psychological context in which the painful stimulus is delivered (Jones, 1997, Price and Harkins, 1992; Wade et al, 1996) and it this way it is open to a great deal of variation. The variability in the pain unpleasantness scores should not have affected the outcome of the ANOVAs, however, as the test remains robust when equal group numbers are used (Winer et al, 1991).

The outcomes of both components of pain assessment indicated that subjects required time to familiarise themselves with the testing procedure and that the results of the initial test may not have been reflective of their pain perception. Neither of the null hypotheses could be rejected. The significant F ratios for the effect of time with both pain measures (intensity $F=16.88$; d.f.=14,56; $p<0.001$; unpleasantness $F=14.97$; d.f.=14,56; $p<0.01$) indicated that, as in experiment 2, the test was serving its purpose in producing measurable levels of pain.

The results of the experiment indicated that repeated exposure to the experimental procedure decreased measures of pain perception and supported the findings of Pertovaara et al (1984). It was only in the 1st test that subject groups rated both mean pain intensity and mean pain unpleasantness higher at minute 1 than in

successive time assessment points and this may just have been due to the initial shock of experiencing the pain sensations. The graphs of the individual subject pain scores in Figures IX(i)-(iii) and X(i)-(iii) in Appendix 3 showed that all the subjects rated their pain intensity higher in minute 1 of the 1st test than in either test 2 or 3 but for the pain unpleasantness scores the high minute 1 score in the 1st test may have been attributable to the exceptionally high score given by subject number 1. It can be stated, however, that the graphs of the mean VAS pain scores (Figures VII and VIII) generally represented an accurate trend in reporting of both the mean pain intensity and mean pain unpleasantness scores. These graphical trends were reflected in the statistical analysis of the data as the similar shape of each line (representing the 1st, 2nd and 3rd test) meant that there was no statistically significant interaction effect between the different tests (i.e. there was no statistically significant difference between the tests that was dependent on time). The statistically significant test effect with the mean pain intensity scores can be seen in Figure VII as the scores in test 1 were noticeably higher than in either of the successive tests. The same degree of difference between the tests was not evident with the mean pain unpleasantness scores (Figure VIII).

Aspects of the results of this experiment may have been be due to decreased anxiety in the subjects as the test procedure became more familiar or they gained greater familiarity with the pain assessment tools. In order to decrease the amount of variation in pain reporting between testing sessions in later experiments an introductory session was set up which exposed the subjects to the procedure that

they would be experiencing. In the introductory session the subjects were able to see the instrumentation and feel the sensations that the ischaemic pain tourniquet test produces. Based on the results of the present experiment, the subjects received only a couple of minutes exposure to the pain induction procedure during the introductory session. The pain scores indicated that it was primarily the initial shock to the painful stimulus that caused the irregular high pain scores to be given.

10.8 : Conclusions

(1) Subjects in the present experiment rated their pain lower (intensity and unpleasantness) in successive exposures to the test, with the greatest difference being noted between the 1st and 2nd test.

(2) Erratic pain scores given by subjects in the initial minutes of the first test suggested the need for an introductory session to be set up in future experiments.

Chapter 11 : Experiment 4 - Investigation of the effect of high frequency TENS on pain intensity and pain unpleasantness of the ischaemic pain tourniquet test using healthy female volunteers. Subject control versus experimenter control of TENS.

11.1 : Introduction

The word 'control' can be used in the global sense to mean 'to exercise power over' or 'to regulate'. With regards to pain research, Thompson (1981) defined control as "the belief that one has at one's disposal a response that can influence the aversiveness of an event". Control can therefore take many forms ranging from forewarned knowledge regarding the event (Staub et al, 1971) to the perceived ability to physically prevent a noxious stimulus from occurring (Weisenberg et al, 1985). Within the context of the present study, however, control was considered to mean the

ability of either the subject or the experimenter to alter the intensity dial on the TENS machine.

Control has been found to be an important factor in determining the response to pain (Kanfer and Seidner, 1973; Staub et al, 1971; Thompson, 1981; Toomey et al, 1991 and Weisenberg et al, 1985) (see Section 5.5) and the neurophysiological rationale supporting pain as a multidimensional experience recognises that the context in which a painful stimulus is received can alter the resultant pain perception (see Section 3.4). Neurophysiological research has provided evidence to support the view that psychological variables such as control can influence both 1st and 2nd stage pain perception. It has been proposed that altering a person's attention whilst they are experiencing pain can reduce their 1st stage pain perception by directly stimulating supraspinal target sites of the medial ascending nociceptive tracts (Guilbaud et al, 1994; Lima, 1997). This can result in activation of brainstem descending inhibitory mechanisms in areas including the cingulate gyrus and so decrease sensory-discriminative and motivational-affective components of pain perception (Lima, 1997). No studies investigating the influence of control on pain perception have been carried out specifically with TENS although the modality has been suggested as being suitable for testing such a relationship (Toomey et al, 1991). An aspect of control which is particularly relevant to TENS because of its use by patients in their own homes is the issue of who controls the current intensity, the therapist or patient.

Some studies investigating the use of TENS with chronic pain have been carried out with the therapist controlling the current intensity (Deyo et al, 1990; Lehmann et al 1986), while others have examined the use of the modality when controlled by the patient in their own home (Ellis, 1995; Johnson et al, 1991a and 1991b). Diversity regarding control is also evident in trials involving acute pain. Smith et al (1986) reported that women with post-caesarean pain controlled the TENS intensity themselves, while Conn et al (1986) reported that post-operative patients had the TENS intensity controlled by the hospital staff.

The difficulty in carrying out experiments within the clinical environment in a controlled manner highlights the necessity for laboratory based TENS studies. In the laboratory situation the ischaemic model of experimental pain induction has been used by researchers in the past to investigate the pain-relieving effects of TENS (see Section 6.5 and Table 1). None of the papers reviewed investigating the use of TENS on the ischaemic pain model have addressed the issue of control of the current intensity. The study methodologies did not always make it clear who was controlling the current intensity during the TENS application but all of the studies suggested that either the subject or the experimenter was consistently responsible for altering the current intensity throughout the TENS procedures.

The studies which tested the efficacy of TENS using experimental ischaemic pain covered a range of different parameters such as current frequency, current intensity,

electrode placement and treatment duration (see Section 6.5 and Table 1). The results of these studies have been inconsistent and this may have been due to differences in experimental design and parameter selection. There is inconclusive evidence for a relationship between specific current parameters and optimal pain-relieving effect and positive outcomes were received with both high frequency (Woolf, 1979) and low frequency (Roche et al, 1984; Walsh et al, 1995) currents. A high frequency current was selected for the present experiment and a low current intensity (sensation threshold) was maintained throughout the TENS application based on the rationale outlined in Section 7.4.4.

11.2 : Aims

The aims of this experiment were to (1) investigate the efficacy of high frequency (100Hz) TENS using the selected experimental procedure and (2) investigate if the efficacy of high frequency (100Hz) TENS is affected by the degree of perceived control that the subject is given over the TENS current intensity. These aims were not listed in order of priority.

11.3 : Design

Each subject was tested on three separate occasions approximately 48 hours apart. An introductory session was also included for each subject prior to their first exposure to the test to familiarise them with both the pain induction procedure and the TENS machine. All subjects experienced each of the three testing conditions; no

TENS (n=12), experimenter controlling TENS (n=12), and subject controlling TENS (n=12). The order in which subjects received the three different conditions was randomised to minimise order effects. The randomising procedure involved writing all 6 of the possible ordering combinations on separate pieces of paper. Each combination was written twice to bring the total number of pieces of paper to 12. A person not familiar with the study was then asked to pull out one of these pieces of paper from a container and match it to a subject number. After a piece of paper containing an order combination was selected from the container, it was not replaced. The procedure was repeated until each of the twelve subjects had been assigned an ordering combination.

11.4 : Methodology (Experimental procedure shown in Appendix 13)

11.4.1 : Materials and instrumentation (Photographs in Appendix 8 and Appendix 12)

The same materials and instrumentation as used in experiment 2 including:

* TENS machine (Endomed 482, Enraf Nonius Delft)

* 2 silicone rubber electrodes + sponge pads (6cm x 4cm)

* Micropore™ adhesive tape

11.4.2 : Subject Recruitment

The same subject recruitment procedure was used as in experiments 1-3. Twelve healthy female volunteers (mean age 21.3 years; range 20-24 years) were recruited from Queen Margaret College student population. There were no drop-outs from the study.

11.4.3 : Ethics

Ethical approval was granted by Queen Margaret College Ethical Committee before commencing the study. The same information sheet and consent form (except timetabling alterations) were used as in previous experiments.

11.4.4 : Introductory session

Subjects attended an initial introductory session approximately 48 hours before the first testing session which involved them being shown the pain induction equipment and the pain assessment scales. They were then exposed to the pain induction procedure (see Section 11.4.5) but the cuff was only inflated for a period of 2 minutes. All subjects also had the TENS electrodes put in place and experienced the current at the selected parameters (see Section 11.4.6). The TENS current was switched on for a total of 4 minutes - 2 minutes prior to pain induction and the 2 minutes during cuff inflation. During this period the experimenter adjusted the current intensity until the subject reported it to be 'just perceptible'.

11.4.5 : Pain Induction

The same pain induction procedure was used as in experiment 3.

11.4.6 : TENS

The TENS machine calibrated was checked before the experiment began. This involved passing a selected current frequency through the oscilloscope and ensuring that the frequency on the TENS machine matched that being registered by the oscilloscope. The two readings were found to be comparable on the first calibration attempt and the TENS machine did not have to be re-calibrated. Subjects receiving TENS had 2 padded electrodes (dampened with water) attached; one placed adjacent to C6 / 7 on the affected side, and the other over Erb's point (a point approximately 2 cm inferior to the clavicle two-thirds distally along its length on the same side). Both these electrodes were secured in place using Micropore™ adhesive tape. In each case the parameters of TENS incorporated a rectangular, symmetrical biphasic current with frequency 100Hz and pulse width 200μs. The duration of TENS stimulation totaled 30 minutes - application began 15 minutes prior to pain induction and continued throughout the cuff inflation period. Throughout this stimulation time the intensity was altered by either the subject or experimenter, as appropriate, until the subject reported the TENS sensation to be "just perceptible".

11.4.7 : Pain Assessment

The same pain assessment procedure was used as in experiments 3.

11.4.8 : Data analysis

The same statistical tests were used as outlined in experiment 2. The factors being tested in the two separate (intensity and unpleasantness) 2-factor analysis of variance (ANOVA) for repeated measures were experimental conditions (no TENS, experimenter controlling TENS, subject controlling TENS) and time (one minute intervals x 15). A 2-factor ANOVA for repeated measures was also selected to investigate the difference in mean current intensities used between the experimenter and subject control conditions.

11.5 : Hypotheses

The following hypotheses were tested in experiment 4:

(I) Hypothesis (H_1)

There will be a statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; experimenter controlling 100Hz TENS; subject controlling 100Hz TENS.

Null Hypothesis (H_O)

There will be no statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; experimenter controlling 100Hz TENS; subject controlling 100Hz TENS.

(II) Hypothesis (H_2)

There will be a statistically significant difference in VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; experimenter controlling 100Hz TENS; subject controlling 100Hz TENS.

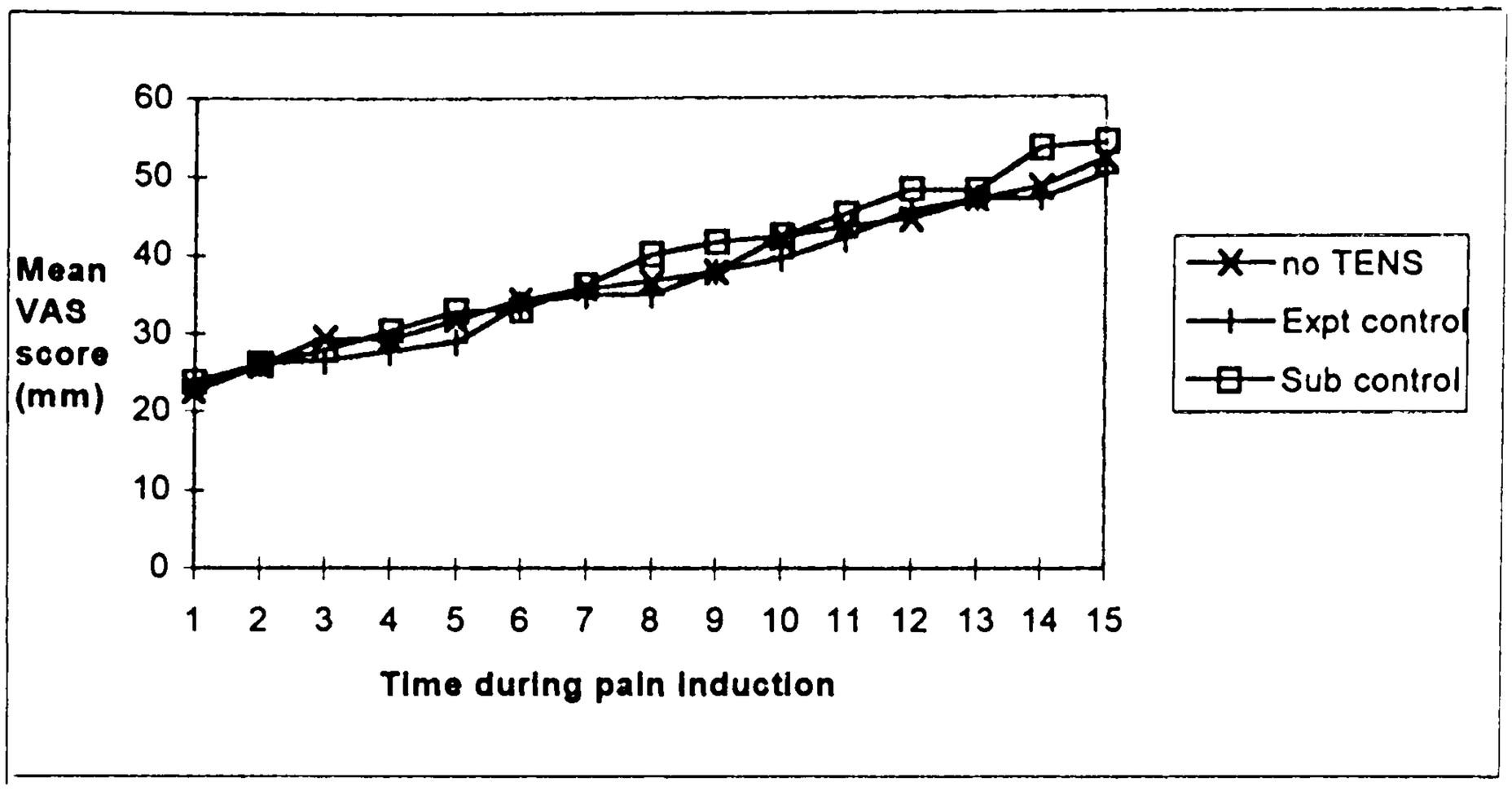
Null Hypothesis (H_O)

There will be no statistically significant difference in VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; experimenter controlling 100Hz TENS; subject controlling 100Hz TENS.

11.6 : Results

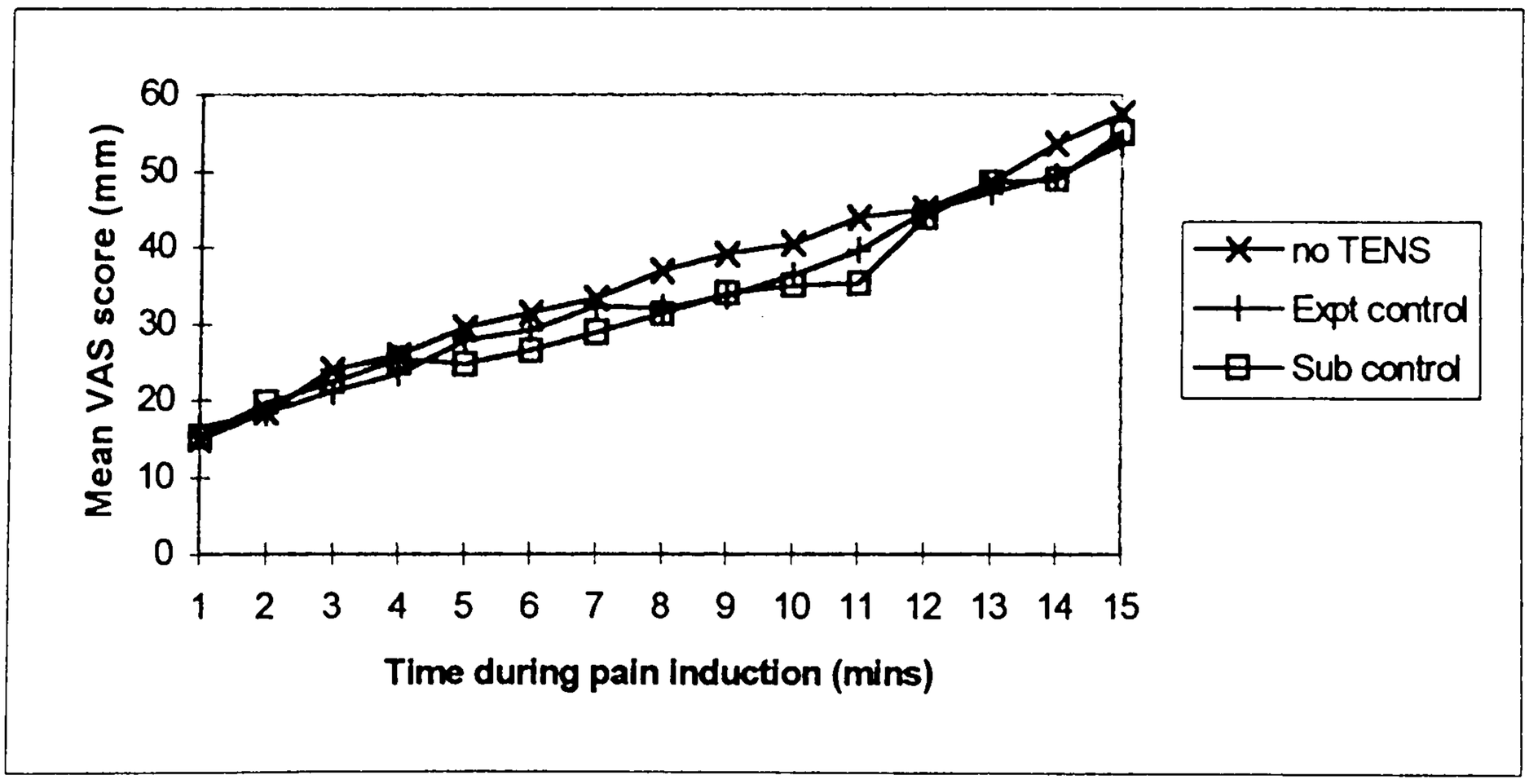
The graphs and tables of data for experiment 4 are shown either here in the text or in Appendix 4. From the graph showing the VAS intensity scores for all 3 conditions (Figure XI on the next page) it can be seen that the subject groups, irrespective of treatment condition, reported a mean increase in pain intensity over time during pain induction. Each of the 3 treatment conditions started marking the VAS intensity scales at a similar point but by the end of the pain induction period the subject group controlling the TENS current intensity gave higher mean pain intensity scores than either the experimenter control condition or the condition receiving no TENS.

Figure XI : Mean VAS pain intensity scores for all 3 conditions in experiment 4 (100Hz TENS)



The graph of the mean VAS unpleasantness scores (Figure XII below) showed that in all 3 treatment conditions mean pain unpleasantness was rated lower than mean pain intensity at the start of the pain induction period.

Figure XII : Mean VAS pain unpleasantness scores for all 3 conditions in experiment 4 (100Hz TENS)



All the conditions followed a similar upward trend in mean pain reporting over time while the cuff was inflated, with the no TENS condition marking the unpleasantness scales slightly higher than the 2 conditions receiving TENS. At the end of pain induction the condition receiving no TENS reported the highest mean pain unpleasantness score, with all 3 conditions displaying mean scores slightly higher than those marked on the VAS intensity scales at the final minute of pain induction.

The Shapiro-Wilk test (Table 4f in Appendix 4) showed normality of distribution for most of the scores, with the VAS intensity scores (experimenter control condition - minute 1) possessing only one value ($p=0.04$) which fell just below the accepted statistical significance value of $p\leq0.05$. The VAS unpleasantness scores (Table 4h in Appendix 4) possessed three values when the same test of normality was used (no tens condition - minute 1; subject control condition - minutes 1 and 2). The results of the Hartley test suggested that homogeneity of variance could be assumed with the intensity scores ($F=2.24$; d.f.=45,11; $p<0.05$) but not with the unpleasantness scores ($F=4.76$; d.f.=45,11; $p>0.05$).

The results of the ANOVA (Table 4a on the next page) showed that the mean pain intensity scores could be seen to increase with time though this increase was not significantly different between the three conditions ($F=0.60$; d.f.=28,308; $p=0.946$).

Table 4a : ANOVA Table for VAS pain intensity scores in experiment 4 (100Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	531.40	2	265.70	0.22	0.806
Error (Within + Residual)	26904.51	22	1222.93		
Effect of Time					
Time	41568.49	14	2969.18	24.90	< 0.001
Error (Within + Residual)	18362.09	154	119.23		
Interaction (ConditionxTime)					
Condition x Time	514.65	28	18.38	0.60	0.946
Error (Within + Residual)	9374.77	308	30.44		

The results also showed that, as with the mean VAS intensity scores, the mean VAS unpleasantness scores (Table 4b below) followed a similar mean increase over time but with no statistically significant difference between the three conditions (F=0.66; d.f.=28,308, p=0.907).

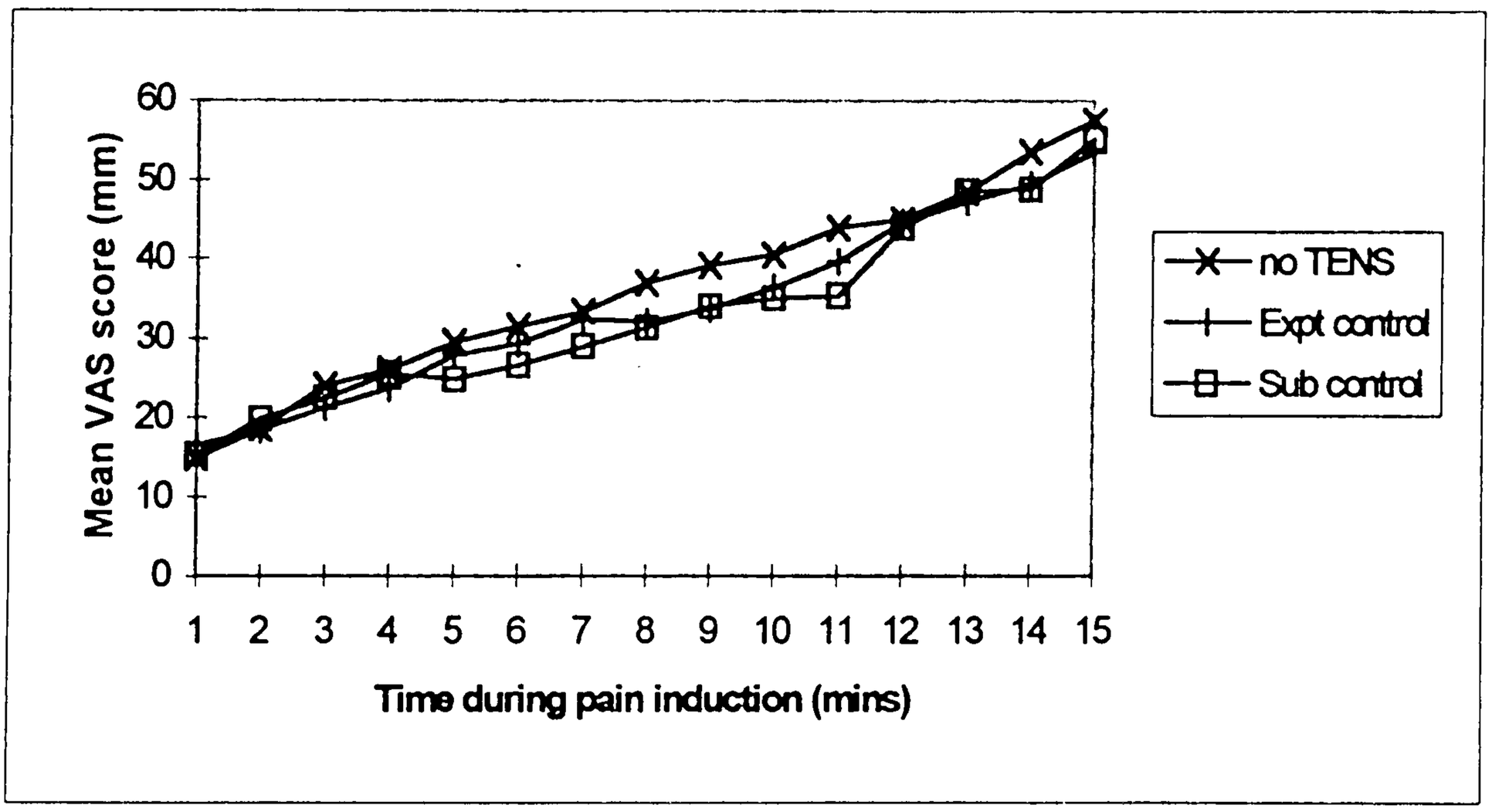
Table 4b : ANOVA Table for VAS pain unpleasantness scores in experiment 4 (100Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	1030.23	2	515.12	0.28	0.755
Error (Within + Residual)	39790.08	22	1808.64		
Effect of Time					
Time	69258.83	14	4947.06	28.32	<0.001
Error (Within + Residual)	26905.74	154	174.71		
Interaction (ConditionxTime)					
Condition x Time	881.43	28	31.48	0.66	0.907
Error (Within + Residual)	14690.26	308	47.70		

Both pain components possessed a significant F ratio on the effect of time (intensity F=24.90; d.f.=14,154; p=0.946; unpleasantness F=28.32; d.f.=14,154; p=0.907).

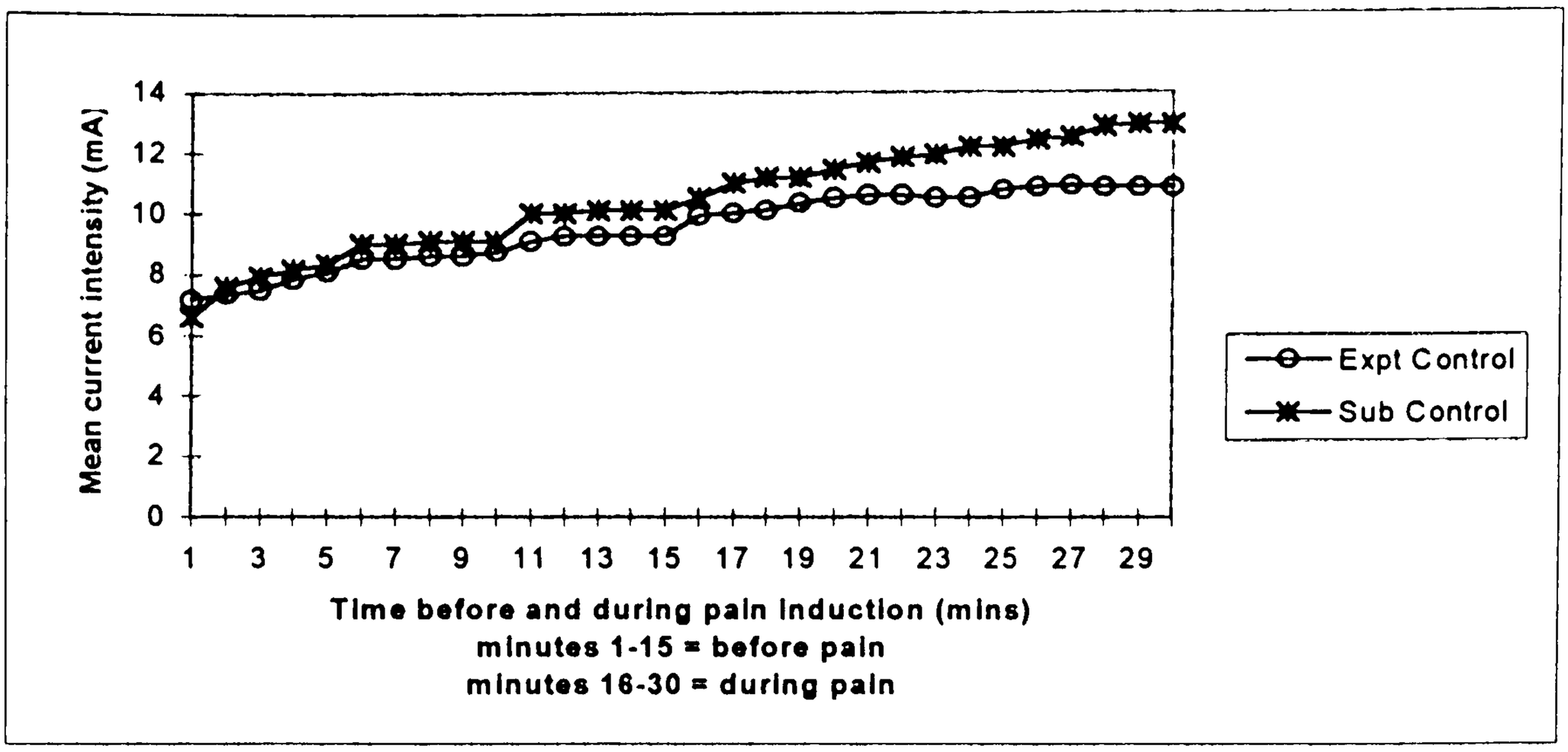
Figure XII below showed the mean current intensities used by both the experimenter and subject control conditions before and during pain induction. The graph showed that both conditions used similar levels of current in the 15 minutes before pain induction (both increase in steps) but once the pain was induced the subject control condition began to administer a noticeably higher level of current intensity than the experimenter control condition, with the difference becoming greater pain induction time increased.

Figure XII : Mean VAS pain unpleasantness scores for all 3 conditions in experiment 4 (100Hz TENS)



Results of the ANOVAs (Tables 4c and 4d in Appendix 4) reflected the graphical findings of Figure XIII shown on the next page, with no statistically significant difference in mean current intensities being found between the experimenter and subject control conditions ($F=0.21$; d.f.=1,11; $p=0.655$) either before or during pain induction.

Figure XIII : Mean currrent intensities (mA) before and during pain induction in experiment 4 (100Hz TENS)



N.B. In figure XIII above minute 16 represents the 1st minute of pain induction.

A statistically significant effect of time was found during the same period ($F=25.71$; d.f.=14,154; $p<0.001$) but this effect was not significant with respect to the control condition ($F=1.43$; d.f.=14,154; $p=0.144$). The ANOVA results for the 15 minutes during pain induction showed no statistically significant effect of condition ($F=1.73$; d.f.=1,11; $p=0.216$) but a statistically significant effect of condition with respect to time ($F=2.79$; d.f.=14,154; $p=0.001$).

11.7 : Discussion

The aims of the present study were to (1) investigate the efficacy of high frequency (100Hz) TENS using the selected experimental procedure and (2) investigate if the efficacy of high frequency (100Hz) TENS is affected by the degree of perceived control that the subject is given over the TENS current intensity. The experimental

hypotheses were based on these aims and the results of the study showed no statistically significant difference in VAS pain intensity or VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; experimenter controlling 100Hz TENS; subject controlling 100Hz TENS. Neither null hypothesis, therefore, could be rejected.

The results implied that the subjects rated their pain similarly regardless of the different conditions they were being tested under and this was reflected in the similarity of the data obtained for each of the conditions (Tables 4e-4h in Appendix 4). The means and standard deviations were comparable between the conditions for both pain and unpleasantness scores but, as observed in experiment 3, there was a greater variance with the unpleasantness scores (reflected in the Hartley test). As before, this could be attributable to unpleasantness, based on neurophysiological pain mechanisms, being subject to greater levels of pain modulation (Fields, 1987; Guilbaud et al, 1994; Jones, 1997; Lima, 1997). The variability in the pain unpleasantness scores, as already mentioned in experiment 3, should not have affected the outcome of the ANOVA as the test remains robust when equal group numbers are used (Winer et al, 1991).

The results suggested that control of the current intensity in the present experiment had no effect on mean VAS scores of pain intensity or pain unpleasantness. With regards to the efficacy of TENS, the results suggested that high frequency (100Hz)

TENS was no more effective in relieving pain (intensity or unpleasantness) than no TENS at all. A possible reason, therefore, for no statistically significant effect being found with the variable of control of the current intensity could be due to the ineffectiveness of the TENS. The inability of TENS in the present experiment to decrease mean pain scores (intensity or unpleasantness) meant that, regardless of who controlled the current intensity, no pain-relief was achieved. Analysis of the mean current intensities used by the experimenter and subject control conditions suggested that when the subjects were given an opportunity to control the current intensity themselves, they gave themselves higher mean levels of current intensity in an attempt to find pain-relief. In this sense control of the current intensity could be thought of as being "in the hand as well as the head" as subjects, when in control themselves, had the ability to increase the amount of peripheral afferent input they were receiving from the TENS.

The results of the previous studies using TENS with experimental ischaemic pain supported the use of the pain model in testing the efficacy of TENS and suggested that current frequency could be a determining factor to the experimental outcome. In the study by Walsh et al (1995) TENS at 4Hz was shown to produce a pain-relieving effect while TENS at 110Hz was found to be no more effective than no TENS at all (a similar result to the present experiment). Foster et al (1995) reported a trend, although the difference was not statistically significant at the selected p value of less

than or equal to 0.5, towards a greater pain-relieving effect using a low frequency current (4Hz) than that with a high frequency (110Hz) current.

It is important, however, not to be led by majority opinion as the results of these studies may have been dependent on the pain assessment tool used. Roche et al (1984) reported an increase in pain tolerance time following high frequency TENS compared to a control condition of no TENS (see Table 1). Similar findings were also reported by Woolf (1979) using pain tolerance times as an outcome measure with the ischaemic pain test (see Table 1). It could be, therefore, that pain tolerance time produce different outcomes than when VASs are employed or that other methodological variables (for example, cuff pressure or exercise intensity) were responsible for the variation in results. The issue of current frequency, however, cannot be dismissed as it has been found to be a determining factor, although not always statistically significant, in the outcome of TENS studies with the experimental ischaemic pain model. For this reason it was considered appropriate to repeat the same experimental procedure using a low frequency TENS current.

11.8 : Conclusions

(1) High frequency (100Hz) TENS was found to be no more effective in relieving pain (intensity or unpleasantness) than no TENS at all.

(2) Control of the current intensity, whether by the experimenter or the subject, had no effect on mean VAS pain scores (intensity or unpleasantness).

Chapter 12 : Experiment 5 - Investigation of the effect of low frequency TENS on pain intensity and pain unpleasantness of the ischaemic pain tourniquet test using healthy female volunteers. Subject control versus experimenter control of TENS.

12.1 : Introduction

The results of experiment 4 showed that (1) high frequency (100Hz) TENS had no statistically significantly greater effect on mean VAS pain scores (intensity or unpleasantness) than no TENS at all and that (2) differences in control of the current intensity had no statistically significant effect on VAS pain intensity or VAS pain unpleasantness scores. The results of the previous experiment therefore indicated that high frequency (100Hz) TENS had no effect on decreasing the intensity or unpleasantness of experimentally induced ischaemic pain regardless of whether the experimenter or the subject controlled the current intensity.

Research with TENS using the ischaemic model of experimental pain has not conclusively established optimal current parameters for pain-relief, with positive TENS outcomes being found with a range of current and methodological variables including electrode placement and treatment duration. With regards to the variable of current frequency, Woolf (1979) obtained positive outcomes using a high frequency current (although not statistically supported) while papers comparing high and low frequency currents have produced evidence supporting the use of low frequency currents (Foster et al, 1995; Walsh et al, 1995) (see Section 6.5 and Table 1). The results of Foster et al (1995) and Walsh et al (1995), although not always reaching statistical significance, have suggested that low frequency currents produce a greater pain-relieving effect than high frequency currents with the ischaemic experimental pain model. The influence of TENS current frequency on pain perception is therefore still under debate and warranted further investigation. The present experiment followed a similar procedure to that used in experiment 4 except a low current frequency (5Hz) was used.

12.2 : Aims

It was the aims of this experiment to (1) investigate the pain-relieving efficacy of low frequency (5Hz) TENS and (2) investigate if the pain-relieving efficacy of low frequency (5Hz) TENS is affected by whether the experimenter or the subject is given control over the TENS current intensity. These aims were not listed in order of priority.

12.3 : Design

The same experimental design was used as in experiment 4.

12.4 : Methodology (Experimental procedure shown in Appendix 13)

12.4.1 : Materials and instrumentation (Photographs in Appendix 8 and Appendix 12)

The same materials and instrumentation were used as in experiment 4.

12.4.2 : Subject Recruitment

The same subject recruitment procedure was used as in experiments 1-4. Twelve healthy female volunteers (mean age 20.25 years; range 18-25 years) were recruited from Queen Margaret College student population. There were no drop-outs from the study

12.4.3 : Ethics

Ethical approval was granted by Queen Margaret College Ethical Committee before commencing the study. The same information sheet and consent form as used in experiments 1-4 (except timetabling alterations) were used.

12.4.4 : Introductory session

The same procedure for the introductory session was used as in experiment 4 except that the TENS was applied at a frequency of 5Hz instead of 100Hz.

12.4.5 : Pain Induction

The same pain induction procedure was used as in experiments 3 and 4.

12.4.6 : TENS

The TENS procedure was the same as in experiment 4 except that the TENS frequency was 5Hz (all the other current parameters remained the same).

12.4.7 : Pain Assessment

The same pain assessment procedure was used as in experiments 2-4.

12.4 : Data Analysis

The same statistical tests were used as outlined in experiment 2. As in the previous experiment (experiment 4) the two factors in the separate ANOVAs (intensity and unpleasantness) were experimental conditions (no TENS, experimenter controlling TENS, subject controlling TENS) and time (one minute intervals x 15). A 2-factor ANOVA for repeated measures was also selected to investigate the difference in mean current intensities used between the experimenter and subject control conditions.

12.5 : Hypotheses

The following hypotheses were tested in experiment 5:

(I) Hypothesis (H_1)

There will be a statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; experimenter controlling 5Hz TENS; subject controlling 5Hz TENS.

Null Hypothesis (H_O)

There will not be a statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; experimenter controlling 5Hz TENS; subject controlling 5Hz TENS.

(II) Hypothesis (H_2)

There will be a statistically significant difference in VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; experimenter controlling 5Hz TENS; subject controlling 5Hz TENS

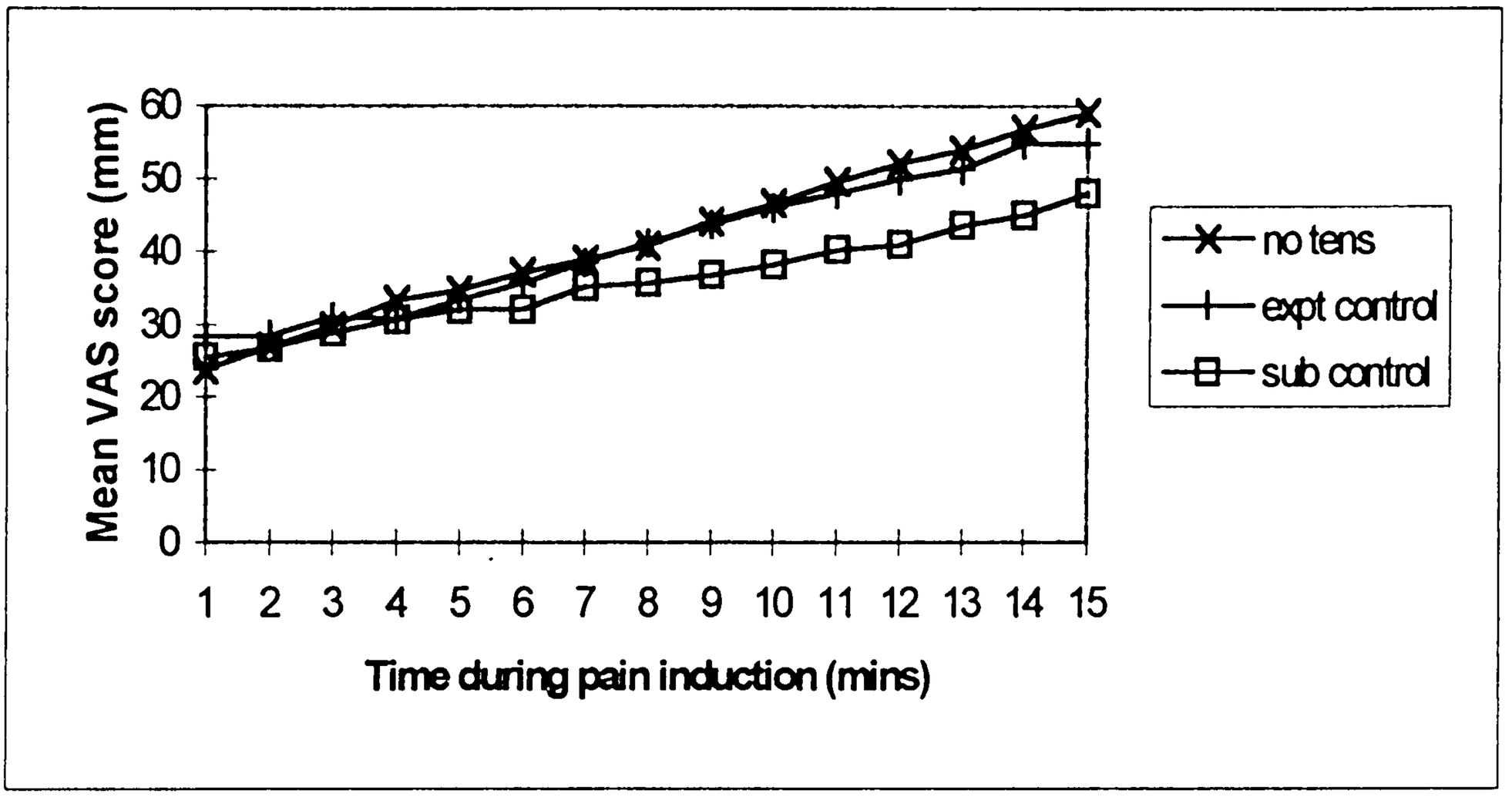
Null Hypothesis (H_O)

There will not be a statistically significant difference in VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; experimenter controlling 5Hz TENS; subject controlling 5Hz TENS.

12.6 : Results

The graphs and tables of data for experiment 5 are shown either here in the text or in Appendix 5. The mean VAS intensity scores during pain induction for all 3 conditions are shown below in Figure XIV.

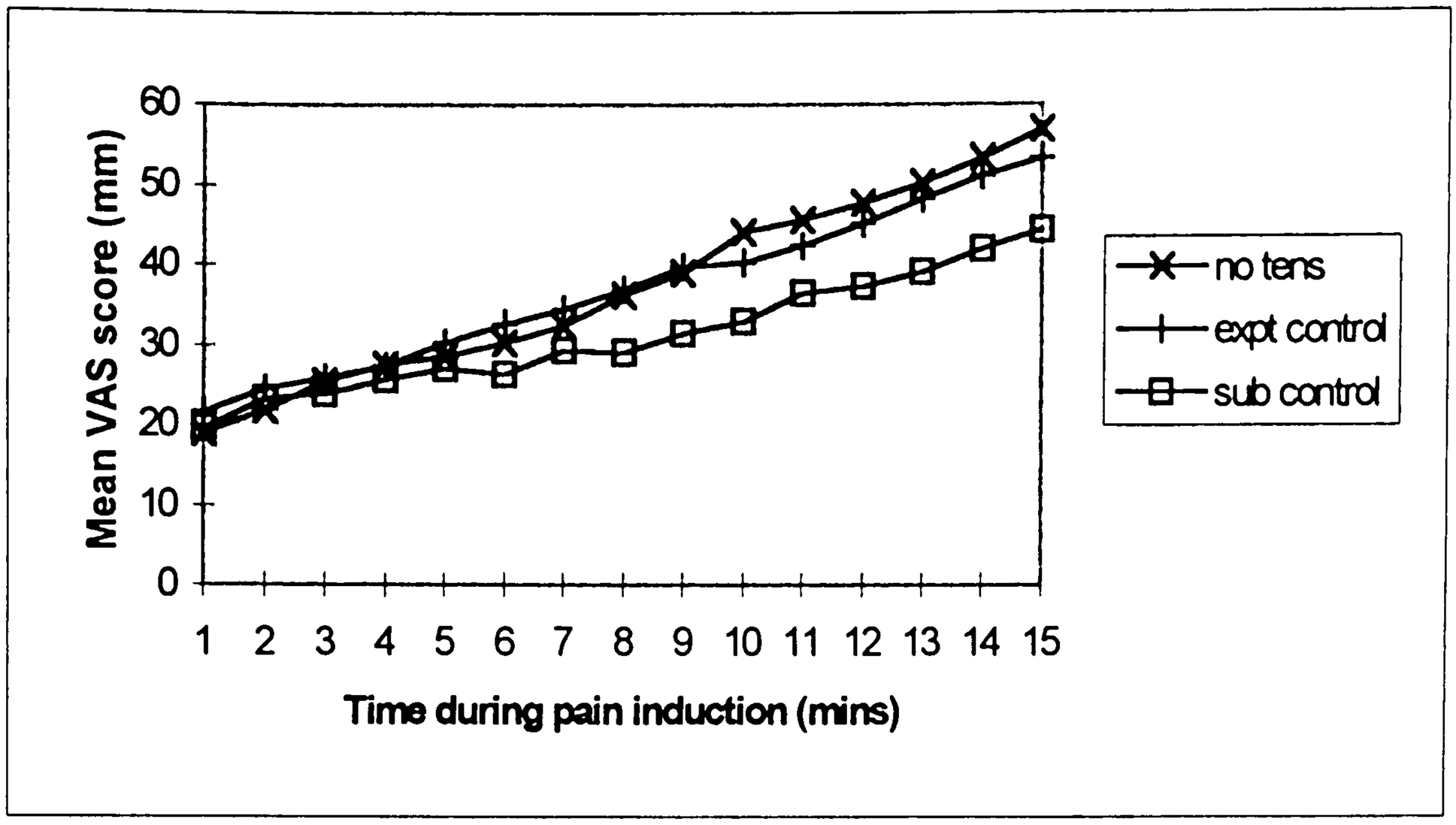
Figure XIV : Mean VAS pain intensity scores for all 3 conditions in experiment 5 (5Hz TENS)



The scoring in all of the conditions was very similar in the first 3 or 4 minutes and then the subject control condition began to give lower mean pain scores than the other two conditions. The mean difference between the subject control condition and the other 2 conditions (experimenter controlling TENS and no TENS) became greater as the pain duration increased.

Regarding the VAS pain unpleasantness scores, Figure XV on the next page showed the mean scores during pain induction for all 3 conditions.

Figure XV : Mean VAS pain unpleasantness scores for all 3 conditions in experiment 5 (5Hz TENS)



Subject groups in all conditions rated mean pain unpleasantness lower than mean pain intensity in the first minute of pain assessment. After approximately 5 minutes of cuff inflation the subject control condition began to rate pain unpleasantness lower than the other 2 conditions (experimenter controlling TENS and no TENS). At the end of the pain induction period the no TENS condition gave the highest mean pain unpleasantness scores with the subject control condition giving the lowest.

The Hartley test suggested that homogeneity of variance could not be assumed by either the intensity ($F=2.87$, d.f.=45,11; $p>0.05$) or unpleasantness ($F=4.80$; d.f.=45,11; $p>0.05$) scores. Normality of data, however, was achieved by all the data when calculated by the Shapiro-Wilk test.

A 2-factor analysis of variance (ANOVA) for repeated measures was used to investigate the relationship between the VAS intensity scores and the experimental conditions. The results of the ANOVA (Table 5a below) showed no statistically significant difference in VAS mean pain intensity scores between the 3 conditions in the study (subject controlling 5Hz TENS; experimenter controlling 5Hz TENS; no TENS).

Table 5a : ANOVA Table for experiment 5 VAS pain intensity Scores (5Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	3611.88	2	1805.94	3.08	0.066
Error (Within + Residual)	12904.26	22	586.56		
Effect of Time					
Time	41147.73	14	2939.12	42.78	<0.001
Error (Within + Residual)	10580.13	154	68.7		
Interaction (ConditionxTime)					
Condition x Time	1854.46	28	66.23	3.76	<0.001
Error (Within + Residual)	5428.08	308	17.62		

There was, however, a statistically significant interaction effect ($F=3.76$; d.f.=28,308; $p<0.001$). This means that there was a statistically significant difference between the conditions that was dependent on time. The effect of time on increasing VAS intensity scores was also significant ($F=42.78$; d.f.=14,154; $p<0.001$).

A test of simple main effects was carried out manually on the VAS intensity scores to identify the time points at which the differences between the conditions were statistically significant. These were found to be minutes 9-15 and are shown in Table 5e in Appendix 5. Post-hoc Scheffe tests were then manually performed

to identify between which conditions the differences lie. The Scheffe tests (Table 5b below) showed that the mean VAS pain intensity scores were lower in the subject control condition compared to the experimenter control condition and the condition receiving no TENS.

Table 5b : Scheffe Test for experiment 5 VAS pain intensity scores (5Hz TENS)

Time	no TENS / expt control (F)	no TENS / sub control (F)	expt control / sub control (F)
Minute 9	0.02	6.92*	6.22*
Minute 10	0.02	8.60*	7.81*
Minute 11	0.30	10.10*	6.92*
Minute 12	0.55	14.72*	9.60*
Minute 13	0.72	12.30*	7.06*
Minute 14	1.59	16.22*	7.66*
Minute 15	1.88	13.48*	5.30

* = statistically significant ($p \leq 0.05$)

The differences between mean scores in the experimenter control condition compared to the condition receiving no TENS became statistically significant from the 9th minute until the end of the pain induction period with the exception of the 15th minute. At this point the difference between the mean scores in the subject control condition and the experimenter control condition was not statistically significant.

A separate 2-factor analysis of variance (ANOVA) for repeated measures was used to investigate the relationship between the VAS unpleasantness scores and the experimental conditions. The ANOVA (Table 5c on the next page) showed no statistically significant difference between the conditions ($F=3.00$; d.f.=2,22; $p=0.071$).

Table 5c : ANOVA Table for experiment 5 VAS pain unpleasantness scores (5Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	4124.54	2	2062.27	3.00	0.071
Error (Within + Residual)	39790.08	22	1808.64		
Effect of Time					
Time	47527.99	14	3394.86	52.98	<0.001
Error (Within + Residual)	9868.86	154	64.08		
Interaction (ConditionxTime)					
Condition x Time	2092.57	28	74.73	3.33	<0.001
Error (Within + Residual)	6907.92	308	22.43		

The statistically significant interaction effect (F=3.33; d.f.=28,308; p<0.001), however, means that there was a statistically significant difference between treatment conditions that was dependent on time. As with the intensity scores, there was a significant F ratio with the effect of time (F=52.98; d.f.=14,154; p=0.001).

A test of simple main effects and post hoc Scheffe tests were carried out as before except using the VAS unpleasantness scores. The test of Simple Main Effects identified that differences between the experimental conditions could be found at minutes 10, 13 and 15. Minutes 12 and 14 were included in the Scheffe test as their F values fell just below the critical value of 3.00 (see Table 5f in Appendix 5). The results of the Scheffe test (Table 5d on the next page) showed that the mean VAS pain unpleasantness scores were lower in the subject control condition than in the condition receiving no TENS.

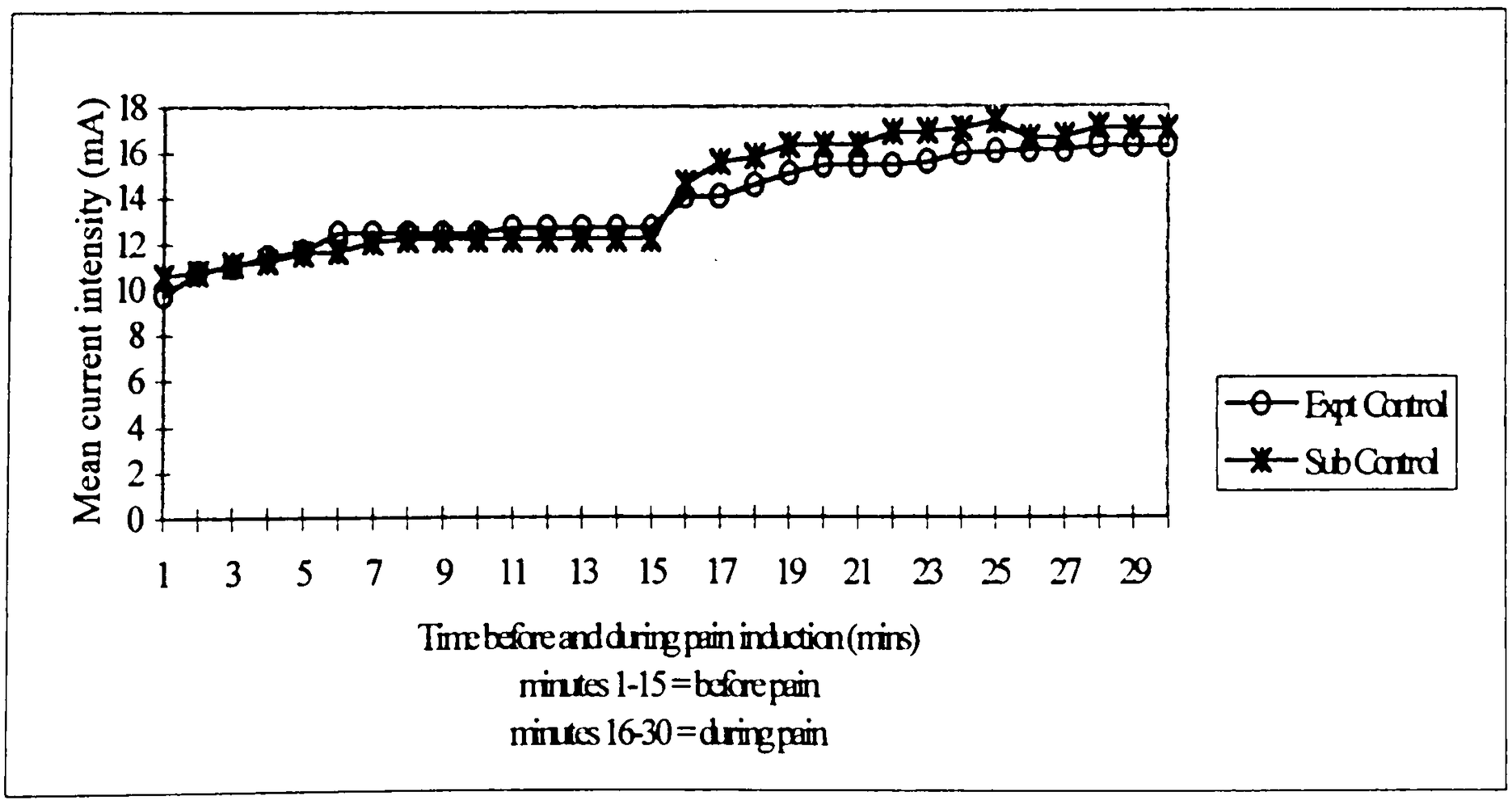
Table 5d : Scheffe Test for experiment 5 VAS pain unpleasantness scores (5Hz TENS)

Time	no TENS / expt control (F)	no TENS / sub control (F)	expt control / sub control (F)
Minute 10	2.03	6.80*	1.40
Minute 12	1.61	6.28*	1.53
Minute 13	1.28	6.68*	2.10
Minute 14	1.66	7.54*	2.13
Minute 15	2.40	9.51*	2.35

* = statistically significant ($p \leq 0.05$)

These differences in means were statistically significant from the 10th minute until the end of pain induction, apart from the 11th minute when the differences were not statistically different. Differences between experimenter control and no TENS and between subject control and no TENS were not shown to be statistically significant. Figure XVI below showed the mean current intensities used by the experimenter and subject control conditions both before and during pain induction.

Figure XVI : Mean current intensities (mA) before and during pain induction in experiment 5 (5Hz TENS)



N.B. In figure XVI above minute 16 represents the 1st minute of pain induction.

The graph showed that both the experimenter and subject control conditions administered higher intensities of current during pain induction compared to the 15 minutes before but that similar levels of current intensity were used by both conditions over the full 30 minute period. The similarity in mean current intensities by the experimenter and subject control conditions was reflected in the results of the ANOVAs (tables 5g and 5h shown in Appendix 5), with no statistically significant effect of control condition being found either before ($F=0.05$; d.f.=1,11; $p=0.831$) or during ($F=0.33$; d.f.=1,11; $p=0.575$) pain induction.

12.7 : Discussion

The results of the present experiment showed that there was a statistically significant difference in both mean VAS pain intensity and mean VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; experimenter controlling 5Hz TENS; subject controlling 5Hz TENS. Both null hypotheses were therefore rejected.

The results of this experiment suggested that the degree of perceived control that a subject had over current intensity influenced mean VAS scores of pain intensity and pain unpleasantness using the selected experimental procedure. The present experiment showed, with regards to the VAS mean pain intensity scores, that there was no statistically significant difference in scores given by the experimenter control condition and those in the no TENS condition. Statistically significant differences, however, were found between the subject control condition and the

other two experimental conditions. Results of the post-hoc tests supported the observation that the subject group, when given control of the TENS current intensity, rated their mean pain intensity lower than when either in the experimenter control group or the no TENS condition. The results indicated that the subject group in the present experiment rated their mean pain intensity lowest when they controlled the TENS current intensity themselves. The results also showed that the subject control condition, but not the experimenter control condition, was more effective in reducing mean VAS pain intensity scores than the no TENS condition. In the present experiment using a low frequency current, therefore, experimenter control of the TENS current intensity was no more effective in reducing mean pain intensity than no TENS at all.

A slightly different result was found with the pain unpleasantness VAS scores, with the Scheffe test producing insufficient evidence to show a statistically significant difference between the experimenter control condition and the condition receiving no TENS. A possible explanation for this may be that the Scheffe test was too conservative to detect small but overall statistically significant differences (Winer, 1991). Increased variance in the unpleasantness scores could explain the reason why mean differences between conditions were not detected. This suggested that while there may have been a relatively small pain-relieving effect, with regards to the VAS pain unpleasantness scores, the statistical power of the test may not have been sufficient to reveal these mean differences as statistically significant. The argument that there may be small pain-relieving effects of low frequency TENS is consistent with an interpretation of the

findings of Foster et al (1995) who reported a possible trend towards a pain-relieving effect in the absence of statistical significance.

The results of the present experiment indicated that the pain-relieving efficacy of low frequency (5Hz) TENS, with respect to both the pain intensity and pain unpleasantness scores, was dependent on who controlled the current intensity. TENS, in the present experiment, was found to be effective in relieving pain when the subjects controlled the current intensity. Analysis of the mean current intensities (Tables 5g and 5h in Appendix 5) used by the experimenter and subject control conditions before and during pain induction showed that there was no statistically significant difference between the levels of current intensity used by the experimenter and subject control conditions during the full 30 minute measurement period. This outcome was in contrast with the results found in experiment 4 where the subject control condition administered statistically significantly higher amounts of high frequency current to themselves than the experimenter control condition during pain induction. It could have been that, in the present experiment using low frequency TENS, subjects did not have to increase the current intensity to find pain-relief as the TENS was effective in reducing pain intensity and pain unpleasantness scores when compared to the no TENS condition. The results therefore suggested that subject control of the pain intensity was more effective in reducing mean VAS scores of pain intensity and pain unpleasantness than the experimenter control condition because the TENS was perceived to be effective in relieving pain.

The proposed theoretical effect of psychological variables such as control on 1st stage pain perception has been discussed in Section 3.4 and it has been suggested that the context in which a stimulus is delivered may have an influence on the sensory-discriminative (pain intensity) and motivational-affective (pain unpleasantness) components of the pain response. In the present experiment the results indicated that both components of pain were influenced to a similar degree when the subjects controlled the current intensity. It could be proposed that the subjects were perhaps unable to distinguish between the two VAS scales and so marked them both similarly but the difference in variance between the two sets of data (see Tables 5j and 5l), as well as the questionnaire responses from a comparable subject group in experiment 2, gave evidence to support the view that the subjects were able to distinguish between pain intensity and pain unpleasantness and mark the scales accordingly.

The results of experiment 4, when compared with the results of the present experiment, raised the question as to why different outcomes were found. The results of experiment 4, which used a high frequency current, found that TENS was not effective in relieving pain regardless of whether the experimenter or subject controlled the current intensity. A possible reason for the results could be that the subjects noticed qualitative differences between the high frequency current and the low frequency currents which in turn influenced their perceived efficacy of the TENS in relieving pain. It has been suggested that giving subjects control of the current intensity decreased pain perception with the 5Hz current but not the 100Hz TENS current because the latter was not perceived to be effective

in relieving pain. It could therefore be suggested that the pain-relieving efficacy of TENS was dependent on qualitative differences noticed between high and low current frequencies.

Low frequency currents are thought to be more effective than higher frequency currents in stimulating motor, as well as sensory afferent fibres at a given current intensity (Low and Reed, 1990; Thompson and Woolf, 1994) and, therefore, it is a possibility that the subjects in the present experiment experienced different sensations than with the 100Hz current. The results of the present experiment, when compared with experiment 4, indicated that there could indeed be a qualitative difference in the subjects' perception between the 5Hz and 100Hz currents. This in turn may have influenced the effectiveness of each of the TENS currents in relieving pain. Observation of the graphs showing mean current intensities used in experiments 4 and 5 (Figures XIII and XVI) indicated that subjects used higher levels (mA) of current with the low frequency current than the high frequency current. These figures cannot validly be compared statistically as they were taken from different subject groups in separate experiments. It was therefore the aims of the next study to (1) compare the pain-relieving effects of TENS when subjects are in control of both a low frequency (5Hz) and high frequency (100Hz) current and (2) identify if subjects perceived there to be any qualitative differences between the two currents and, if so, how this influenced how the two currents were applied.

12.8 : Conclusions

(1) Low frequency (5Hz) TENS when the subjects controlled the current intensity was found to be more effective in relieving pain (intensity or unpleasantness) than when the experimenter controlled the current intensity.

(2) Low frequency (5Hz) TENS when the experimenter controlled the current intensity was found to be no more effective in relieving pain (intensity or unpleasantness) than when no TENS was used at all.

(3) The results of the present experimenter, when compared with those in experiment 4, suggested that giving subjects control of the current intensity decreased pain perception (intensity and unpleasantness) only when the TENS current was perceived as being effective in relieving pain.

Chapter 13 : Experiment 6 - Investigation of the effect of high and low frequency TENS on pain intensity and pain unpleasantness of the ischaemic pain tourniquet test using healthy female volunteers.

13.1 : Introduction

The results of experiment 4 and 5 showed that subject control of the TENS current intensity statistically significantly decreased pain scores (intensity and unpleasantness) during the ischaemic pain tourniquet test when a low frequency current was used (5Hz) but not when a high frequency (100Hz) current was used. The only difference between the two experiments was the frequency at which the TENS currents were delivered and therefore it was suggested that a possible reason for experiment 4 and experiment 5 obtaining different results may have been due to qualitative differences between the two currents which resulted in subjects perceiving one to be less effective than the other in relieving pain. It was also suggested that qualitative differences between the two currents may have caused

subjects to select higher intensities of one type of current over another. A questionnaire was designed specifically for the present experiment to assess perceived qualitative differences between the two currents (Appendix 14). A comparison of actual current intensities selected (mA) was also recorded during the pain induction procedure and this data was analysed to investigate if, indeed, subjects did select statistically significantly higher current intensities of either a high or low frequency TENS current.

13.2 : Aims

The aims of this study were to (1) compare the pain-relieving effects (pain intensity and pain unpleasantness) of TENS when subjects are in control of both a low frequency (5Hz) and high frequency (100Hz) current and (2) identify if subjects select different levels of current intensity depending on the current frequency. These aims were not listed in order of priority.

13.3 : Design

The same experimental design was used as in experiments 4 and 5. All subjects experienced each of the three testing conditions; no TENS (n=12), high frequency (HF = 100 Hertz) TENS (n=12), and low frequency (LF=5 Hertz) TENS (n=12). The same randomisation procedure was followed as in previous experiments.

13.4 : Methodology (Experimental procedure shown in Appendix 13)

13.4.1 : Materials and instrumentation (Photographs in Appendix 8 and Appendix 12)

The same materials and instrumentation were used as in experiments 4 and 5.

13.4.2 : Subject Recruitment

The same subject recruitment procedure was used as in previous experiments. Twelve healthy female volunteers (mean age 21.58 years; range 19 - 30 years) were recruited from Queen Margaret College student population. There were no drop-outs from the study.

13.4.3 : Ethics

Ethical approval was granted by Queen Margaret College Ethical Committee before commencing the study. The same information sheet and consent form (except timetabling alterations) as used in previous experiments were used.

13.4.4 : Introductory session

The introductory session followed the same procedure as in experiments 4 and 5 except that the subject, and not the experimenter, adjusted the TENS current intensity until they reported it to be 'just perceptible'.

13.4.5 : Pain Induction

The same pain induction procedure was used as in experiments 3-5.

13.4.6 : TENS

The same TENS procedure was used as in experiments 4 and 5 except that all subjects experienced both the 100Hz and 5Hz frequency TENS currents during different testing sessions. The subjects were in control of the TENS intensity in each case. The digital readout display of the TENS machine was covered throughout all the experiments so that only the experimenter, and not the subject, could read which frequency they were receiving, or how much current they were giving themselves.

13.4.7 : Pain Assessment

The same pain assessment procedure as in experiments 3-5 was used except that once the cuff was deflated after the final test each subject was asked to complete a questionnaire, constructed specifically for the experiment, to assess the qualitative aspects of the 2 TENS currents used (Appendix 14).

13.4.8 : Data analysis

The same statistical tests were used as outlined in experiment 2. Two separate 2-factor analysis of variance (ANOVA) for repeated measures were used to investigate the relationship between the VAS (intensity and unpleasantness) scores and the experimental conditions (no TENS, HF TENS, and LF TENS). A 2-factor ANOVA was also carried out to compare the amount of current (milliamps) selected by the subjects using the different TENS frequencies.

13.5 : Hypotheses

The following hypotheses were tested in experiment 6:

(I) Hypothesis (H_1)

There will be a statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; subject controlling 100Hz TENS; subject controlling 5Hz TENS.

Null Hypothesis (H_o)

There will not be a statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; subject controlling 100Hz TENS; subject controlling 5Hz TENS.

(II) Hypothesis (H_2)

There will be a statistically significant difference in VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; subject controlling 100Hz TENS; subject controlling 5Hz TENS.

Null Hypothesis (H_o)

There will not be a statistically significant difference in VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; subject controlling 100Hz TENS; subject controlling 5Hz TENS.

(III) Hypothesis (H_3)

There will be a statistically significant difference in the current intensities selected in the 5Hz TENS condition and the 100Hz TENS condition.

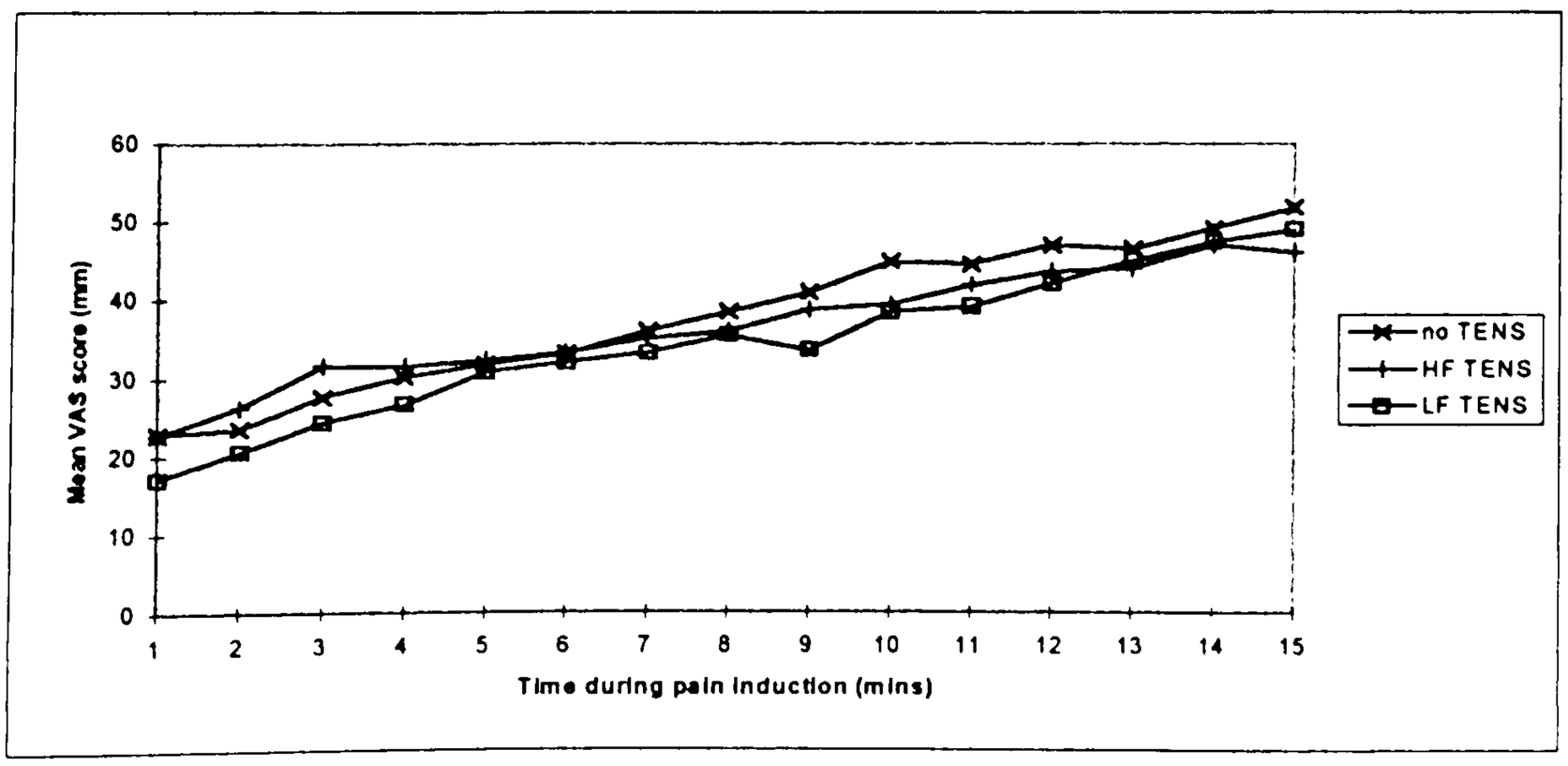
Null Hypothesis (H_O)

There will not be a statistically significant difference in the current intensities selected in the 5Hz TENS condition and the 100Hz TENS condition.

13.6 : Results

The data and graphs for experiment 6 are shown either here in the text or in Appendix 6. The graph showing the mean VAS intensity scores for all 3 conditions (Figure XVII below) indicated that all the subject groups, irrespective of treatment condition, reported an increase in mean pain intensity over time during pain induction.

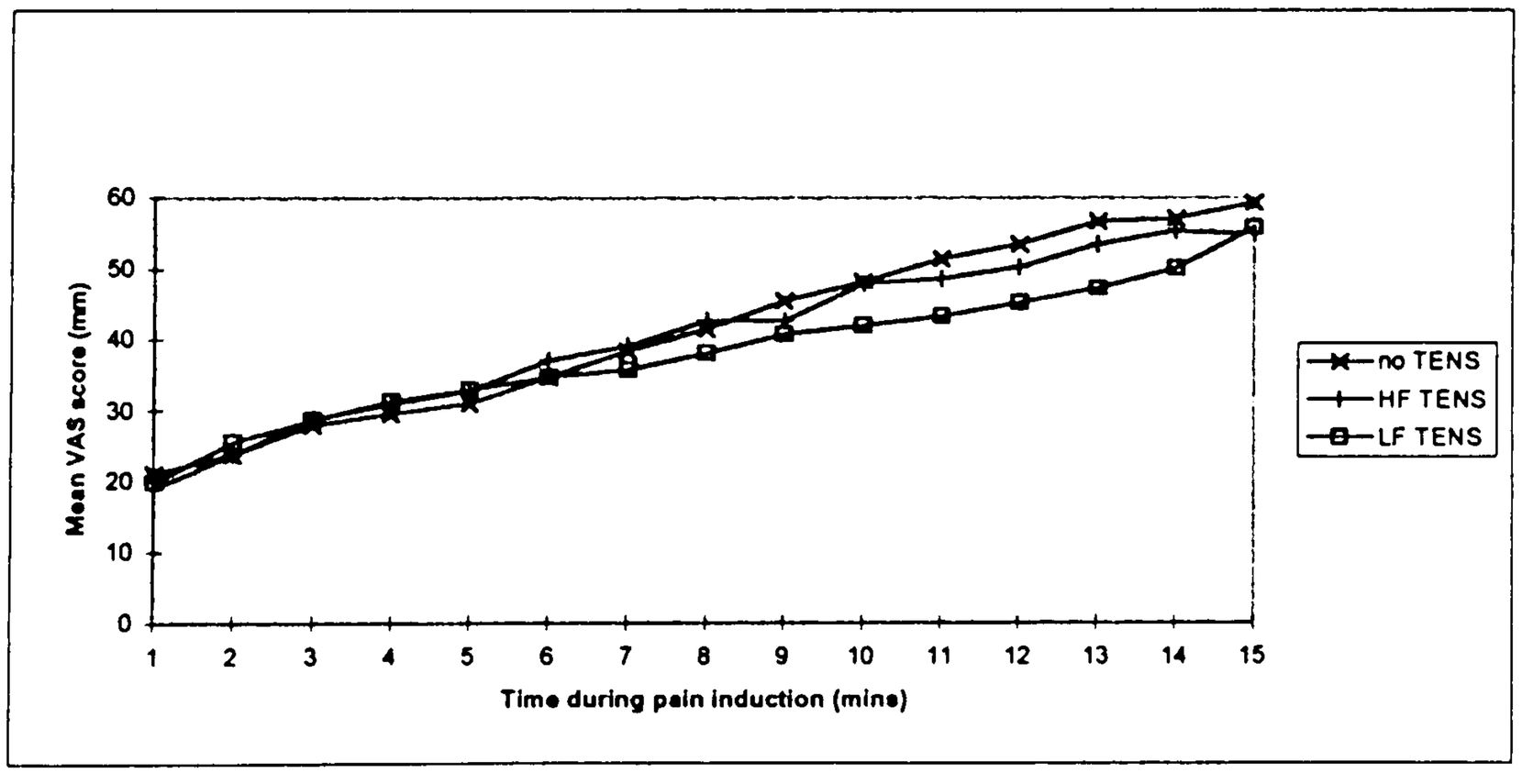
Figure XVII : Mean VAS pain intensity scores for all 3 conditions in experiment 6



The low frequency TENS condition gave lower mean pain intensity scores than the other two conditions over the first 14 minutes of the test, while the no TENS condition gave the highest mean pain intensity scores (not significant) from minute 7 onwards.

The graph of the mean VAS unpleasantness scores (Figure XVIII below) showed that all 3 treatment conditions rated mean pain unpleasantness very similarly at the start of the test but from minute 7 onwards the low frequency TENS condition rated their mean pain unpleasantness lower (not significantly) than the other two conditions.

Figure XVIII : Mean VAS pain unpleasantness scores for all 3 conditions in experiment 6



The Hartley test suggested that homogeneity of variance could not be assumed with the intensity ($F=4.86$; d.f.=45,11; $p<0.05$) or unpleasantness ($F=4.24$; d.f.=45,11; $p<0.05$) scores in the present experiment. The Shapiro-Wilk test (Tables 6h and 6j in Appendix 6) showed normality of distribution for the majority of scores, with the VAS intensity data possessing only a small selection of scores whose p value fell

below the 0.05 level. These scores were at minutes 13-15 in the no TENS condition, minutes 1 and 5-15 in the high frequency TENS condition and minute 15 in the low frequency TENS condition. VAS intensity scores that were close to the p=0.05 level were all in the high frequency TENS group and were at minutes 2 (p=0,.07), 3 (p=0.08) and minute 4 (p=0.06). The high frequency TENS condition, as with the VAS intensity scores, gave the largest number of deviations from the normal distribution of data with the VAS unpleasantness scores. These were found at minutes 1-6 and minute 9, with minutes 7 and 12 just falling outwith the accepted p value. There were no scores in this category in the no TENS experimental condition and, in the low frequency TENS condition, scores with a p value less than or equal to 0.05 were found at minutes 1 and 2 (minutes 3, 6 and 8 were just above this value).

The raw and mean VAS scores for pain intensity in each of the 3 conditions (no TENS; subject controlling 100Hz TENS; subject controlling 5Hz TENS) are shown in Tables 6g and 6h in Appendix 6. The results of the ANOVA (Table 6a on the next page) showed that the mean pain intensity scores could be seen to increase with time ($F=16.05$; d.f.=14,154; $p<0.001$) though this increase was not significantly different between the three conditions ($F=1.19$; d.f.=28,308; $p=0.239$).

Table 6a : ANOVA table for VAS pain intensity scores in experiment 6

VAS INTENSITY	SS	d.f.	MS	F	p
Effect of TENS					
TENS	1199.13	2	599.56	0.28	0.761
Error (Within + Residual)	47809.10	22	2173.14		
Effect of Time					
Minute	37825.16	14	2701.80	16.05	< 0.001
Error (Within + Residual)	25920.93	154	168.32		
Interaction					
TENS x Minute	1103.49	28	29.41	1.19	0.239
Error (Within + Residual)	10213.63	308	33.16		

The results also showed that, as with the VAS intensity scores, the mean VAS unpleasantness scores (Table 6b below) followed a similar mean increase over time ($F=18.98$; d.f.=14,154; $p<0.001$) but with no statistically significant difference between the three conditions ($F=1.36$; d.f.=28,308, $p=0.110$).

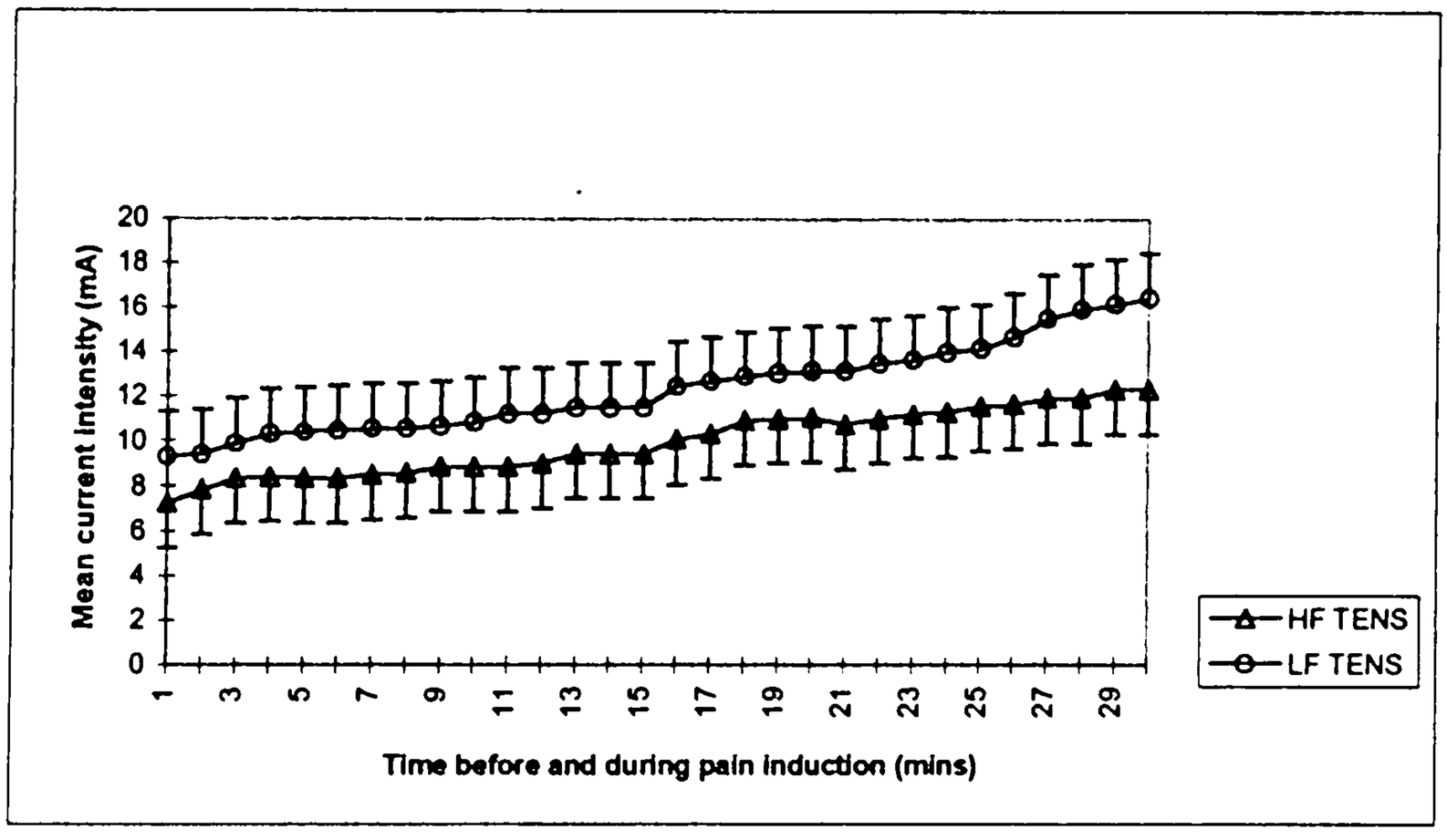
Table 6b : ANOVA table for VAS pain unpleasantness scores in experiment 6

VAS UNPLEASANTNESS	SS	d.f.	MS	F	p
Effect of TENS					
TENS	1023.11	2	511.56	0.19	0.829
Error (Within + Residual)	59584.40	22	2708.38		
Effect of Time					
Minute	64162.19	14	4583.01	18.98	< 0.001
Error (Within + Residual)	37190.39	154	241.50		
Interaction					
TENS x Minute	1607.39	28	57.41	1.36	0.110
Error (Within + Residual)	12993.10	308	42.19		

Analysis of the current intensities used in the two conditions receiving TENS (Tables 6c and 6e) showed that the subjects selected significantly higher intensities of low frequency current both before ($F=7.38$; d.f.=1,11; $p=0.020$) and during ($F=7.21$; d.f.=1,11; $p=0.021$) pain induction although neither showed a statistically

significant interaction effect (before F=0.67; d.f.=14,154; p=0.805: during F=1.34; d.f.=14,154; p=0.188). Simple main effects, carried out manually, identified that the TENS current intensities were statistically different at all of the 15 one minute intervals before pain induction (see Table 6d in Appendix 6) while during pain induction statistically significant differences were found from minutes 7 to 15 (see Table 6f in Appendix 6). These results, including the standard deviations, are illustrated in Figure XIX below (the means and standard deviations for the current intensity data are shown in tables 6l and 6n in Appendix 6).

Figure XIX : Mean current intensities for both 100Hz and 5Hz TENS in experiment 6 (including standard deviations)



N.B. In figure XIX above minute 16 represents the 1st minute of pain induction.

A summary of the questionnaire findings are shown in Table 6o in Appendix 6. All the subjects, except one, thought the two currents felt different from each other. This was reflected in the descriptors selected for each current, with the lower frequency current being described as "pulsed" and "throbbing", while the sensation produced by the higher frequency current was described as "fuzzy" and "buzzing".

Only 7 of the 12 subjects felt that they had used a higher intensity with one type of current and, interestingly, 6 of these subjects thought it was with the high frequency current.

13.7 : Discussion

The aims of this study were to (1) compare the pain-relieving effects (pain intensity and pain unpleasantness) of TENS when subjects are in control of both a low frequency (5Hz) and high frequency (100Hz) current and (2) identify if subjects select different levels of current intensity depending on the current frequency. The results of the study showed no statistically significant difference in either mean VAS pain intensity or mean VAS pain unpleasantness scores between the 3 treatment conditions: no TENS; subject controlling 100Hz TENS; subject controlling 5Hz TENS. The first two null hypotheses could not, therefore, be rejected. A statistically significant difference was found, however, between the mean current intensities selected with the 5Hz TENS condition and the 100Hz TENS condition and the third null hypothesis could be rejected. As in previous experiments, deviations from qualities required of parametric data (Hartley test and Shapiro-Wilk test) could be assumed to minimally affect the ANOVA as the statistical test remains robust to such deviations when equal numbers in groups are used (Winer et al, 1991). The outcomes of the present study could therefore be taken to be valid.

Observation of the ANOVA results for the pain intensity and pain unpleasantness scores showed that the p values were 0.239 and 0.110 respectively. In the case of the unpleasantness scores, this level of statistical significance was still relatively high

and, therefore, although the relevant null hypothesis could not be rejected, the result could not be dismissed as representing a strong statistical trend. This trend was reflected in the graph which showed the mean VAS pain unpleasantness scores during pain induction for all 3 treatment conditions (Figure XVIII). The graph indicated that the 5Hz TENS condition gave noticeably lower mean pain unpleasantness scores than the other two conditions, especially in the later stages of pain induction.

The findings of this experiment reinforced those reported in experiment 5 with respect to pain unpleasantness. The mean reporting of pain intensity by the low frequency TENS condition in the present experiment, however, did not reach a high level of statistically significant difference from that in the no TENS condition. Experiment 3 (see Chapter 10) found that, after an initial exposure to the experimental procedure, subjects marked VAS pain scales (intensity and unpleasantness) in a similar manner when repeatedly exposed to the ischaemic pain tourniquet test. It could be proposed, therefore, that in both the present experiment and experiment 5, the pain scores of intensity and unpleasantness were valid and that the decrease in mean pain intensity reported in experiment 5 using low frequency TENS was a weak, non-repeatable effect. None of the studies which have used TENS with the ischaemic pain tourniquet test (Foster et al, 1995; Roche et al, 1984; Walsh et al, 1993; Walsh et al, 1995; Woolf, 1979) used a repeated test design where TENS was applied more than once to the same subject. It is therefore not possible to speculate about whether TENS would have produced similar pain scores as the 1st test exposure if the experiment had been repeated.

The majority of subjects in the study (n=11) did notice qualitative difference between the two frequencies of current and this was identified by the questionnaire responses (see Table 6o). Seven of these subjects felt that the qualitative difference between the two TENS frequencies had caused them to use a higher intensity with one of the currents. Six out of the seven thought they had used a higher intensity of current with the high frequency (100Hz) TENS, with only one subject stating that the low frequency (5Hz) TENS had required a higher intensity of current to reach a 'just perceptible' level. This was in complete contradiction to the actual intensities (mA) selected by all the subjects, with the ANOVA of the intensity scores showing a statistically significant effect of frequency both before ($F=7.38$; d.f.=1,11; $p=0.02$) and during ($F=7.21$; d.f.=1,11; $p=0.021$) pain induction. The low frequency (5Hz) TENS intensity was found to be consistently lower than that of the high frequency (100Hz) TENS and this difference was statistically significant at all 15 one minute time intervals prior to pain induction and from minutes 7-15 during cuff inflation.

It could be suggested that the differences in perceived sensation between the two currents resulted in the dissimilar results being found with the selected levels of intensity. The requirement of higher intensities of current at lower frequencies is supported by Johnson et al (1991a) who found that chronic pain patients required significantly more current to attain sensory threshold, therapy level and pain threshold at 20Hz as opposed to 100Hz TENS. The findings were also in agreement with theoretical electrical principles of TENS and strength-duration curves which propose that at similar pulse durations, low frequency currents require greater

intensities of current than high frequency currents to reach the rheobase (Low and Reed, 1990; Woolf and Thompson, 1994) (see Section 2.4 and Figure 3b). The results of the present experiment therefore supported the evidence that current frequency affects the intensity of current that subjects administer to themselves at a given subjective level such as sensation threshold and this may be due to perceived qualitative differences between high and low frequency TENS currents.

13.8 : Conclusions

(1) Neither null hypothesis regarding mean VAS pain scores was able to be rejected but a strong statistical trend was found with the pain unpleasantness scores, indicating that lower mean VAS scores were given by the subject control condition than either of the other two test conditions (no TENS and experimenter control).

(2) The results of the present experiment suggested that subjects perceived high frequency and low frequency TENS currents differently. This difference in perceived sensation appear to have led subjects to administer different levels of current intensity to themselves when they were controlling the TENS current, with statistically significantly greater mean levels of current being administered when the low frequency current was used.

CHAPTER 14 : DISCUSSION

14.1 : Introduction

A review of the literature at the beginning of this thesis aimed to identify the current state of knowledge in the relevant topic areas. Gaps in the literature with regard to the pain-relieving efficacy of TENS were noted as including; (i) multi-dimensional assessment of both 1st and 2nd stage pain perception, (ii) optimal current frequency of TENS and (iii) the influence of control. A series of six experiments was carried out, based on the gaps identified in the literature, to investigate whether experimenter or subject control of the current intensity influenced the pain-relieving effects (1st stage intensity and unpleasantness) of TENS using an ischaemic model of experimental pain. Experiments 1-3 were carried out to establish appropriate methodologies for the pain induction and pain assessment procedure used in the present study. Experiments 4-6 then went on to investigate the influence of control of the current intensity on pain perception using both a high frequency (100Hz) and a low frequency (5Hz) TENS current.

The findings of experiments 1-6 suggested that the outcomes of the present study would be best discussed under the following headings; research design, experimental pain model, pain assessment, TENS parameters, control, implications for clinical practice, future work and conclusions.

14.2 : Research design

An experimental model of pain induction was selected in the present study. The decision to use an experimental pain model arose from the review of literature. The review of literature identified different methodologies and outcome measures between clinical TENS trials and this has led to conflicting outcomes assessing the efficacy of TENS in the clinical setting. An example of contradictory study outcomes included those reported by Deyo et al (1990) and Marchand et al (1993). Deyo et al (1990) found TENS to be no better than placebo treatment when used with patients with chronic low back pain while Marchand et al (1993) reported that TENS was significantly more effective than placebo in reducing pain intensity immediately following treatment in a comparable subject group (see Sections 5.4 and 6.2 respectively). It has been highlighted in this thesis that it is extremely important, if the pain-relieving efficacy of TENS is to be established, that the mechanisms of effect are identified. Mechanisms of effect cannot be established from clinical trials of varying methodology because comparison of results is too difficult. The necessity and usefulness of clinical trials is not disputed but more rigid control of methodological variables is required if the complex neurophysiological mechanisms involved in TENS are to be identified. The present study was therefore carried out using a controlled experimental design. In

this way the present study design can be viewed as adopting an approach whereby the choice of subjects, TENS parameters and pain assessment procedure aimed to reduce the number of variables which could theoretically have confounded the effects of the variable being investigated (the effect of control of the current intensity). These aspects of the experimental design will be dealt with individually later in the discussion.

There is evidence which supports the view that TENS can act at different levels of neural processing of sensory input, namely spinal cord, brainstem and cortical (see Chapter 4). The modulation of pain perception is dependent on the complex interaction of these mechanisms and is thought to be contributed to by factors such as the TENS current parameters (Eriksson et al, 1979; Garrison and Foreman, 1994), characteristics of the patient group (Richardson, 1994), the patient-therapist interaction and perception of control (Gielen, 1989; Klaber Moffett and Richardson, 1997; Turner et al, 1994). It has been suggested that variables are easier to control during experimental pain induction than in the clinical setting and it has been proposed that intervention under laboratory conditions is necessary to identify mechanisms of analgesic action (Gracely, 1994).

The employment in the present study of an experimental pain model using healthy students from Queen Margaret College was an important aspect of the present study's tightly controlled approach. It was identified in the review of literature, supported by neurophysiological evidence, that psychological variables such as

control can influence both the 1st and 2nd stage of pain perception (Guilbaud et al, 1994, Lima, 1997) (see Sections 3.4 and 5.5). The influence of control on 1st stage pain perception is thought to be a result of stimulation of target sites of the medial ascending tracts (motivational-affective component of pain) (Guilbaud et al, 1994; Lima, 1997) while 2nd stage pain perception is thought to be influenced to a greater extent by cognitive-evaluative cortical processing or so-called placebo effects (Price and Harkins, 1992). The present study, in order to decrease the number of variables which could have masked the effect of control on pain scores chose to assess 1st stage pain perception. Although the 1st stage of pain perception is not greatly affected by placebo effects, it has been shown that the stimulation of the motivational-affective target sites, under the influence of attentional mechanisms, is dependent on the emotional context in which a stimulus is delivered (Lima, 1997). It was therefore considered extremely important in the present study to reduce the number of variables between subjects which could have modulated attentional mechanisms. Marchand et al (1993) reported that, with respect to pain reporting and changes in attention, variations in pain perception can occur due to subjects being placed in an unfamiliar environment. In the present study subjects were all familiar with the environment, experimenter and equipment and this should have minimised variations in attentional mechanisms and placebo effects and maintained them at a comparable level between subjects.

The subject numbers used for the experiments in the present study ranged from between five and twelve. This was in accordance with subject numbers used in

other experimental studies using TENS, taking into consideration variation in study design (Foster et al, 1995; Roche et al, 1984; Walsh et al, 1993; Walsh et al, 1995; Woolf, 1979). The subject numbers were also found to be appropriate for the statistical test employed (ANOVA) as, even with small numbers such as n=5 in experiment 3, the statistical power of the test was calculated as being 0.95 for the pain intensity scores and 0.78 for the pain unpleasantness scores. It was thought that increasing the subject number could have led to methodological bias as large subject numbers are more appropriate when it is necessary to detect a small effect such as a dangerous side-effect in a drug trial. In this instance then, if the null hypothesis of the drug not being harmful is falsely not rejected (Type II error), the drug will be incorrectly considered to be safe. The purpose of the present study was to establish the efficacy of TENS when the current intensity was controlled by (1) the experimenter and (2) the subject. The present study was therefore investigating the pain-relieving effects of TENS under different experimental conditions and it would not have been advantageous to have the actual therapeutic significance of relatively small pain-relieving effects magnified.

14.3 : Experimental pain model

An ischaemic model of experimental pain induction was used in the present study. A summary of popular experimental pain techniques was reviewed in Section 6.4. While each pain model has its own usefulness, the ischaemic pain model was considered the most appropriate pain induction technique for use in the present study due to its standardised procedure, prolonged duration of the painful stimulus and short recovery period. The duration of the ischaemic pain induction

was originally planned as 15 minutes. The drop-out rate in experiment 1 which occurred before this period had elapsed addressed the need to adjust the parameters of the ischaemic pain induction procedure so as to increase the tolerance time to 15 minutes while still producing an appropriate level of pain. This was achieved by decreasing the exercise grip / release time from 2 seconds to 1 second. The mean VAS scores of both pain intensity and pain unpleasantness in experiments 2-6, supported by the graphical and statistical evidence, suggested that the subject groups perceived the experimental ischaemic pain to be progressively more painful (intensity and unpleasantness) as the pain induction time increased, with almost all subjects tolerating the full 15 minutes.

The results of the present study, which distinguished between pain intensity and pain unpleasantness, provided important information about the mechanisms of experimental ischaemic pain. Two mechanisms of action for the ischaemic pain tourniquet test were identified as being due to (1) a build-up of exercise-induced metabolites in the arm and (2) mechanical pressure applied by the cuff (Pertovaara et al, 1984). The first mechanism is activated by noxious levels of chemical by-products of exercise which, based on the properties of afferent nociceptors, stimulate C fibres (Meyer at al, 1994). The second mechanism is thought to occur as a result of noxious levels of mechanical stimulation which therefore stimulate both Aδ and C fibres (Fields, 1987; Meyer et al, 1994). Aδ and C fibres have been found to relay noxious information in the lateral and medial ascending tracts and contribute to the sensory-discriminative and motivational-affective components of the pain response, respectively. The results of experiment 2 in the present study

suggested that the contribution of each of the identified mechanisms was not dependent on the cuff pressure used (200mmHg or 250mmHg) as both pain intensity and pain unpleasantness scores followed similar trends under both experimental conditions (intensity $F=0.22$; d.f.=14,84; $p=0.999$: unpleasantness $F=0.15$; d.f.=14,84; $p=1.000$).

Experiment 3 addressed another important issue regarding the experimental pain model used in the present study - investigating the pain response of subjects when placed under repeated exposures of the pain induction procedure. The graphs of the experimental results (see Figures VII-VIII in Appendix 3) indicated that there was a trend for decreased pain reporting, particularly with the mean pain intensity scores, over repeated test exposures. The mean scores for both pain intensity and pain unpleasantness decreased during successive exposures to the pain induction procedure, with the greatest difference in mean scores being noted between the 1st and 2nd test. Graphs of the individual scores (see Figures IX i-iii and X i-iii) showed that subjects gave higher pain scores in the initial minutes of the first test than in either the second or third. This finding stressed the need for an introductory session which allowed the subjects to experience the pain induction, pain assessment and TENS (when applicable), so reducing the probability of a 'shock' reaction by subjects to the painful stimulus and increasing the probability of obtaining data that was reflective of the subjects' pain response.

The possible disadvantages of a repeated measures experimental design were highlighted in the review of literature when referring to the studies carried out by

Foster et al (1995), Walsh et al (1993) and Walsh et al (1995) (see Section 6.5). In each of these studies all subjects were tested twice, the first time to collect baseline data (ischaemic pain test with no intervention). Test 2, 48 hours later, involved the same method of experimental pain induction except that subjects were assigned to an experimental group to receive some form of treatment intervention. The pain-relieving efficacy of the selected interventions was established in each case by comparing the pain scores (VAS intensity and MPQ) obtained for the two tests (1-way ANOVA and difference scores). The experimental design of these studies therefore made the assumption that the data collected in the first test was a reliable baseline measure upon which to compare pain scores from the second test. The findings of experiment 3 in the present study suggested that the pain measures in the 1st exposure to the test were not consistently representative of the subjects' pain reporting in later tests. If the VAS pain intensity scores were statistically significantly higher in the initial test than in successive exposures, as found in experiment 3, then it would follow that the pain-relieving effects of the interventions would have been magnified. High baseline values mean that pain scores would have decreased in the second test, regardless of the intervention, but simply due to repeated exposure to the test procedure. Valid comparisons could have made between the different interventions being tested in any individual study but the therapeutic significance of a particular intervention may have been over-estimated with the chosen experimental design. To minimise these problems in the present study a cross-over design was used in experiment 2 and a randomisation procedure was used in

experiments 4-6. In this way, although still retaining the repeated measures experimental design, order effects were reduced.

14.4 : Pain assessment

Two important aspects of the present study, based on neurophysiological evidence, were incorporated into the pain assessment procedure; (1) the decision to use a multi-dimensional approach to the assessment of pain perception and (2) the decision to distinguish between 1st and 2nd stage pain perception. The concept of a multi-dimensional pain response is not new and, indeed, has been addressed in both experimental (Duncan et al, 1989; Gracely et al, 1979; Price et al, 1983; Price et al, 1987) and clinical studies (Marchand et al, 1993; Price et al, 1987). Distinguishing between 1st and 2nd stage pain perception, however, is a relatively new concept and although it has been discussed theoretically (Price and Harkins, 1992), differences between the two stages of pain perception have not been considered in any of the reviewed TENS studies in the present thesis (clinical or experimental). It was identified in the review of literature that the subject group and the type of pain being investigated influence the relative input of each of the two stages of pain perception, with 2nd stage playing a larger role in clinical chronic pain conditions (Price and Harkins, Wade et al, 1986). It is therefore important that pain studies base their choice of assessment tool and timing of pain assessment on the specific needs of their study design. It was decided from the review of the literature that, with the present experimental study design using healthy subjects, pain assessment tools would be required which were able to assess 1st stage pain intensity and pain unpleasantness.

Having selected the ischaemic tourniquet model as the most appropriate method of experimental pain induction for the present study, the first experiment was designed to select a suitable measurement tool for assessing 1st stage pain perception (pain intensity and pain unpleasantness). The review of measurement techniques identified the VAS and VRS as tools which could be adapted for the task (see Sections 7.2.1 - 7.2.3) and a comparison was carried out between these two scales in experiment 1. The results showed the scales to produce very similar pain scores, especially with the pain intensity scores (intensity r^2=0.76-100: unpleasantness r^2=0.50-1.00). Discrepancies between the pain unpleasantness data obtained from the VAS and VRS were found at a number of time points but were attributed to the cross-modality procedure used to score the VRS (see Section 8.7). The limitations of both scales were taken into consideration and, based on the time consuming nature of the cross-modality procedure required to give the VRS interval/ratio scoring properties, the decision was made to select the VAS for sole use in the succeeding experiments.

Previous experimenters using the ischaemic pain model (Foster et al, 1995; Roche et al, 1984; Walsh et al, 1993, Walsh et al, 1995; Woolf, 1979) have only measured *pain intensity* during the pain induction period. A number of these studies (Foster et al, 1995; Roche et al, 1984; Walsh et al, 1993, Walsh et al, 1995) selected the MPQ as a multi-dimensional pain assessment tool *after* cuff deflation. Walsh et al (1995) explained the purpose of the MPQ as assessing 'the worst pain experienced' which implied that a cognitive-evaluative (2nd stage)

level of pain perception was measured in the study. The two stages of pain perception were not identified by any of the authors and so it could not be established if the MPQ was meant to be assessing the first or second stage of pain unpleasantness.

Results of the MPQ scores in the study carried out by Walsh et al (1995) were shown graphically in terms of differences between the 1st and 2nd tests and observation of the data indicated that, with both the high and low frequency TENS currents, the affective component of the pain response was decreased to a much lesser extent (between approximately a half and a third) than the sensory component. The difference between the two components was greater when the high frequency TENS current was used. These MPQ results did not correspond with the VAS results found in the present study, with mean pain unpleasantness scores being influenced to a similar extent (relative to mean pain intensity scores) with the high frequency current and to a greater extent with the low frequency current when the subject controlled the pain intensity. This indicated that the VASs used in the present study and the MPQ used in the study carried out by Walsh et al (1995) were assessing different stages of pain perception from each other. This finding reinforces the need for pain studies to identify the stage of pain perception which they aim to assess and choose an appropriate measuring tool.

14.5 : TENS parameters

The pain-relieving efficacy of both a high frequency (100Hz) and low frequency (5Hz) TENS current was investigated in the present study. The results of experiment 4 which investigated the efficacy of high frequency TENS found that the modality was ineffective in reducing either pain intensity or pain unpleasantness. The outcome suggested that 100Hz TENS, when either the subject or the experimenter controlled the current intensity dial, was no more effective in decreasing pain reporting than when no TENS was applied at all ($F=0.60$; d.f.=28,308; $p=0.946$: unpleasantness $F=0.66$; d.f.=28,308; $p=0.907$). In the same experiment, when the levels of current intensity (mA) were investigated, it was found that subjects selected statistically significantly higher levels of current during pain induction when they controlled the current intensity dial themselves as opposed to when the intensity was controlled by the experimenter ($F=2.79$; d.f.=14,154; $p=0.001$). Taking into consideration that neither control condition provided pain-relief (as suggested by the VAS scores) it was proposed that subjects in experiment 4, when given the opportunity to increase the current intensity themselves, did so in an attempt to help relieve their pain, although unsuccessfully. Different results were observed in experiment 5 which investigated the efficacy of low frequency (5Hz) TENS. In this experiment measures of pain intensity and pain unpleasantness were both statistically significantly reduced using TENS when compared with the no TENS condition (intensity $F=3.76$; d.f.=28,308; $p<0.001$: $F=3.33$; d.f.=28,308; $p<0.001$). Interestingly, when investigating the current intensities selected with the low frequency TENS during pain induction, it was found that there was no statistically

significant difference between the subject and experimenter control conditions ($F=0.56$; d.f.=14,154; $p=0.892$). This was interpreted as meaning that, because the low frequency TENS was successful in reducing pain perception (as suggested by the VAS scores), subjects did not have to take advantage of control of the current intensity in order to apply higher levels of current to themselves in search of pain-relief. It should be stressed that, although subjects were requested in each case to only turn up the current intensity until a 'just perceptible' level of stimulation was achieved, as a subjective measure it was based entirely on subject honesty. The mean VAS scores (intensity and unpleasantness) in the present study showed that subjects found the low frequency current, but not the high frequency current, to be effective at a statistically significantly level in decreasing pain perception. It is therefore reasonable to suggest, based on the result that the subject control condition used higher levels of current than the experimenter control condition with the low frequency but not the high frequency TENS current, that perception of current sensation was influenced by the expectation of pain reduction.

The difference in outcomes found between the high and low frequency TENS currents in experiments 4 and 5 respectively can be linked with previous TENS studies which have used the ischaemic pain model (see Section 6.5 and Table 1). The findings of Walsh et al (1995) were in agreement with the findings of the present study, supporting the use of low frequency currents for increased pain-relief using TENS and reporting that high frequency TENS was no more effective in relieving pain than no TENS at all. The results of the present study, however,

posed the question as to why clinical studies such as that carried out by Marchand et al (1993) have found that high frequency currents statistically significantly reduced patient pain perception. Possible reasons for such discrepancies in study outcome include the patient group being assessed and the timing of the pain assessment procedure. Marchand et al (1993) used VASs to assess both pain intensity and pain unpleasantness. Unlike the present study, pain assessment was carried out at a number of time points before and after treatment over a period of six months and was therefore assessing 2nd stage pain perception. The subject group used in the study were chronic low-back pain patients and pain perception would have been greatly influenced by the cognitive-evaluative component of the pain response (Price and Harkins, 1992). The effect that the low-back pain had on the patients' lifestyles and mood states would have influenced the VAS scores but this is not the case with the present study which assessed 1st stage pain perception in healthy subjects. Differences in outcome between the two types of study are therefore to be expected as they were assessing different stages of pain perception in different subject groups.

It is important to stress the reason why the present study chose to assess 1st stage, and not 2nd stage, pain perception. If a positive pain-relieving effect with TENS when the subjects controlled the current intensity had been found with 2nd stage pain assessment in the present study, the result could not necessarily have been attributed to the variable of control. Instead it could have been due to a combination of variables which have been thought to influence 2nd stage pain perception such as subject mood state and subject-experimenter interaction

(Gielen, 1989; Klaber Moffett and Richardson, 1997; Turner et al, 1994). Healthy subjects were used in the present study and so assessing their pain perception *after* the painful stimulus had been removed would not have been reflective of the clinical scenario. The effect of low frequency TENS in decreasing 1st stage pain perception found in the present study when the subjects controlled the current intensity indicates that the variable of control influenced the outcome. The methodology of the present study, using a tightly controlled experimental design, was able to minimise the effect of other possible variables which are thought to influence 1st stage pain perception (e.g. unfamiliar environment). In this way the results of the present experiment indicate that subject control of the current intensity will theoretically decrease pain perception in the clinical situation as 2nd stage pain processing can allow the effects to be magnified.

14.6 : Control

Experiments 4-6 in the present study, as well as looking at the effect of TENS current frequency on pain perception, aimed to also investigate the effect of control of the current intensity on the efficacy of TENS during experimental ischaemic pain induction. No previous studies have incorporated control of the current intensity as a variable in TENS trials. Indeed, with the exception of the study by Walsh et al (1995) who stated that the subjects controlled the TENS intensity, none of the other reviewed experimental ischaemic pain studies reported who controlled the TENS intensity. In light of the aims of the present study, which included investigating the effect of experimenter and subject control of the current intensity on pain perception, it cannot be easily compared with past

research. The pain-relieving efficacy of high and low frequency TENS currents was investigated in experiments 4 and 5 respectively and, with particular reference to the variable of control, the results of the present study indicated that subject control of the current intensity, in conjunction with a low current frequency, optimised the pain-relieving effects of TENS. The low frequency current, but not the high frequency current was found to decrease the perception (intensity and unpleasantness) of experimentally induced ischaemic pain and therefore it is suggested that subject control of the current intensity only optimised pain-relief with TENS when the TENS current was capable of decreasing pain perception.

The present study found that subject control of the current intensity statistically significantly decreased 1st stage pain perception (intensity and unpleasantness) with TENS when a low frequency (5Hz) current was used. The assessment of 1st stage pain perception in the present study allowed mechanisms of pain-relieving effect by TENS which occur below cortical level to be identified. This is because assessment of 1st stage pain perception does not theoretically incorporate significant input from the cognitive-evaluative component of the pain response. It is important to emphasise, therefore, that the pain-relief produced by TENS in the present study was not a placebo response.

The results of experiment 6 which compared the 100Hz and 5Hz TENS currents when the subject controlled the TENS did not reject the null hypothesis that there was no statistically significant difference in VAS pain intensity scores between the 3 treatment conditions: no TENS; subject controlling 100Hz TENS; subject

controlling 5Hz TENS (F=1.19; d.f.=28,308; p=0.239). This was not the same outcome as that obtained in experiment 5 (F=3.76; d.f.=28,308; p<0.001) and suggested that the pain-relieving efficacy of the low frequency TENS current was not a strong repeatable effect. The outcome of each experiment in the present study was based on the decision to reject, or not, the null hypotheses. In order for the null hypotheses in the present study to be operational a statistical significance level of $p \leq 0.05$ was selected. The selection of a p value therefore, although allowing the null hypotheses to be operational, did not allow for identification of statistical trends. A selected level of significance is concerned with helping to define, in very specific terms, what kind of chances are being taken when a decision is made to reject, or not, a null hypothesis (Payton, 1994). A p value of 0.05 therefore presents with a five percent risk of making the incorrect decision. Statistical significance should never be confused with real life significance and, as suggested by Payton (1994), a statistical statement of probability should always be interpreted by human reason. The ANOVA results in experiment 6 (see Tables 6i and 6j - Appendix 6) showed the p values for the effect of TENS frequency over time to be 0.239 (F=1.19; d.f.=28,308) for the pain intensity scores and 0.110 (F=1.36; d.f.=28,308) for the pain unpleasantness scores. In the case of the pain unpleasantness scores, the p value was low enough to propose that there was a difference in perception of pain unpleasantness between the experimental conditions (no TENS, subject controlling high frequency TENS, subject controlling low frequency TENS) and this difference would have been considered statistically significant at the level of p=0.110. Observation of the graphical data (see Figure XVI - Appendix 6) indicated that the low frequency TENS condition

gave lower mean VAS pain unpleasantness scores than the high frequency TENS and no TENS conditions and that this difference was greatest between minutes 10 and 14 inclusive. Mean pain unpleasantness scores were found to be similar between the experimenter control and no TENS conditions. The results of experiment 6, therefore, reinforced the results of experiment 5 which indicated that subject control of the current intensity of low frequency (5Hz) TENS decreased 1st stage pain unpleasantness of experimentally induced ischaemic pain.

Mean current intensities selected by subjects with both TENS current frequencies were also investigated in experiment 6 and it was highlighted that the subject group administered statistically significantly higher mean intensities of low frequency (5Hz) current than high frequency (100Hz) current when controlling the intensity themselves. Possible reasons for this difference in mean current intensity selection were identified in the replies from the questionnaire designed specifically for the study (see Table 6h in Appendix 6). The questionnaire responses identified that 11 out of 12 subjects noticed a qualitative difference between the two currents, with 5 of these subjects reporting that they had perceived one of the currents to be stronger than the other. These subjects then gave descriptions of each of the two currents, with the choice of words indicating that the perceived difference in current strength may have been related to the perceived current sensations. Words used to describe the 5Hz TENS included 'pulsing', 'beating' and 'throbbing' which all correspond with a stimulus applied intermittently (i.e. at a low frequency). The words used to describe the 100Hz current, on the other hand, included 'buzzing', 'fuzzy' and 'tingling' which are

more consistent with a stimulus delivered at high frequency. The questionnaire in experiment 6 also asked subjects if they felt they had selected higher intensities of one current over the other. Of the 7 positive replies, 6 thought they had applied higher intensities of the high frequency TENS in order to achieve a 'just perceptible' level of current sensation. Subjects were asked to achieve a "just perceptible" level of current with both high and low frequency TENS and it follows, therefore, that if subjects thought they were taking more current with the 100Hz TENS, then it felt 'weaker' than the 5Hz TENS and higher intensities were required in order to reach the same level of sensation.

The identification of qualitative differences between the 100Hz and 5Hz currents has implications as to the different pain-relieving effectiveness of one current over the other. Walsh et al (1995) suggested that low frequency currents may operate by producing a 'counter-irritant' effect and this comment was based on the observation that muscle contractions had been produced by the low frequency TENS current in the region of the electrodes. In the present study a low current intensity (sensation threshold) was used and it is therefore extremely unlikely that the current intensity was high enough to produce a muscle contraction. Walsh et al (1995) also suggested that the low frequency TENS current may have reduced pain scores by producing a distraction from the experimental ischaemic pain. The results of experiment 6 indicated that the low frequency current may have been perceived as being stronger than the high frequency current. It is therefore reasonable to suggest, supporting the views of Walsh et al (1995), that the low frequency current in the present study was perceived as being stronger, providing

subjects with a distraction from the ischaemic pain and decreasing their pain perception. This viewpoint is also supported by the findings published by Johnson et al (1991a) who reported that in patients with chronic pain, even those who did not produce a significant decrease in pain reporting with the use of TENS, continued to use the modality stating that "TENS does not reduce my pain, but it distracts, or takes my mind off it". The results of the study by Johnson et al (1991a) have important implications for distinguishing between 1st and 2nd stage pain perception as pain assessment in the study was carried out when the TENS was not *in situ*. Different results may have been found if 1st stage pain assessment *during* the application of TENS had been carried out as the TENS may have provided a distraction from their pain and so decreased their pain perception.

The distraction hypothesis was not, however, the only explanation of the effects. Lima (1997) provided neurophysiological evidence for differences in pain-relieving efficacy between high and low frequency currents. The author proposed that the signals sent supraspinally by lamina 1 neurones may be dependent on the qualitative properties of the stimulus and suggested that stimuli which are perceived to be qualitatively dissimilar activate different distributions of cells within the spinal cord in response to sensory input. This variation in cell activation between different stimuli also implies that qualitative differences between TENS currents involve neurophysiological modulatory mechanisms at spinal cord, brainstem and cortical level which influence pain perception. It was discussed earlier in the thesis (see Section 3.4) that 1st stage pain perception is primarily a reflection of processing of noxious and non-noxious information within the spinal

cord and at the target sites within the brainstem and cortex (Jones, 1997; Lima, 1997). In this respect it is proposed that in the present study subject control of the TENS intensity was more effective with the low frequency current because target sites influencing the effect of control on pain perception (for example, cingulate gyrus and temporal lobe) may have been, to a greater extent, stimulated by the low frequency TENS than by the high frequency TENS.

CHAPTER 15 : IMPLICATIONS FOR CLINICAL PRACTICE AND FUTURE RESEARCH

15.1 : Introduction

The rationale for the present study is laid out in Section 7.4. This methodology is considered appropriate and necessary for the experimental approach used. As with all study designs, from RCTs to single case studies, the method has limitations. These must be addressed if clinical inferences are to be made. A number of issues are raised and are sub-headed in order of their possible effect on the clinical relevance of the present study. These are listed as; model of pain induction, TENS current intensity, subject group, omission of a sham TENS condition and electrode placement. In each instance the present study methodology is compared with the clinical situation and suggestions made as to how this may have influenced study outcome. A final section, based on the limitations and inferences already mentioned, is then presented on other clinical implications of the present study and the possibilities for future research.

15.2 : Model of pain induction

Before the specific limitations of the ischaemic pain tourniquet test are raised, it is important to re-emphasise that experimental pain, regardless of how rigorously the technique is carried out, cannot replicate clinical pain. It is well recognised within the field of pain research that experimental pain is dissimilar to clinical pain both physically and psychologically (Gracely, 1994). In the case of experimental ischaemic pain the painful stimulus is transient in that it is present only once the exercises are performed and lasts until a short time after the cuff is deflated. There is no residual tissue damage to the involved limb and clinical symptoms such as allodynia or hyperalgesia are not present. The transient nature of the stimulus contributes to the psychological disparity between clinical and experimental pain as with the latter the person experiencing the pain knows that there will be no negative lasting effects and that the stimulus can be removed at their request. In this way the person does not experience the same degree of anxiety, depression or suffering that can be associated with clinical pain (Bromm, 1984).

A specific problem with the tourniquet method of experimental ischaemic pain induction is that there is the possibility of sensory disturbances to the involved limb due to nerve compression. This could have the effect of distorting sensory perception distal to the cuff and in turn influence the pain VAS scores. Another implication of nerve compression is that the TENS current may have been unable to stimulate the nerves distal to the cuff. This is discussed in greater detail under 'Electrode placement'.

15.3 : TENS current intensity

The selection of a 'just perceptible' level of current throughout the TENS stimulation in the present study was based on a neurophysiological rationale which aimed to allow TENS, theoretically, to modify pain at a spinal segmental level during both the high and low frequency TENS experiments (for greater detail see Section 7.4.4). In the clinical setting, however, TENS is more commonly used at a level which is perceived by the patient to be strong but comfortable (Frampton, 1996). It could be argued, therefore, that TENS' inability to reduce pain scores using the high frequency (100Hz) current may have been due to there being an insufficient level of current. This is a possibility but cannot be resolved in the present study. It therefore addresses the need for a similar study to be carried out using various different levels of current intensity.

15.4 : Subject group

The subject group used in each of the experiments in the present study were healthy female students from Queen Margaret College and represented a sample population which were of the same sex and of similar age, race and educational status. This population was not, therefore, representative of the clinical situation where patients are socially and demographically different from one another. Inferences as to how a clinical population would have rated their pain using the pain induction model in the present study are difficult to make, taking into consideration that research has indicated that factors such as sex, age and cultural background can influence a person's reporting of pain (French, 1989; Heath and Thomas, 1993). The issue is further complicated by the pain-free status of the

subjects in the present study, making it difficult to compare them to patients experiencing clinical pain.

The results of the present study indicated that greatest pain-relief was achieved when the subject controlled the TENS intensity of a low frequency (5Hz) current and it was suggested that this may have been due to qualitative preferences for that particular current parameter. The subjective nature of the pain experience means that making broad generalisations about pain responses are inappropriate but it is important to be aware of factors thought to influence pain ratings when investigating the outcome of a study.

15.5 : Omission of a sham TENS condition

The treatment conditions used in the present study were either active TENS conditions (subject or experimenter controlling the current intensity) or a non-treatment control condition. During the control condition subjects were not issued with any of the relevant TENS instructions, nor did not have electrodes attached to them, as subjects in the active TENS procedure did. There is, therefore, the possibility that in the instances where the active TENS conditions gave statistically significantly lower pain scores than the control (no treatment) condition that it was the complete process of applying the TENS that produced the result. In other words, the omission of a sham TENS condition in the present study does not allow it to be established if pain-relief from TENS was due to the stimulation of nerves by an electrical current or solely due to the process of having TENS applied. The subjects used in the present study were all familiar

with TENS which would have made it extremely difficult to give an effective sham treatment. The situation was further complicated by the repeated measures design used in the TENS experiments. The use of a sham TENS condition in the present study, if perceived by the subjects as being a sham, could have had the effect of contaminating the succeeding tests and decreasing the validity of the results. It was therefore viewed that the disadvantages of a sham TENS condition in the present study outweighed the advantages. Importantly, what the results of the present study were able to inform us about was whether TENS, under the intensity control of either the subject or experimenter, was more effective in relieving pain than no TENS at all.

15.6 : Electrode placement

The electrode placements used in the present study were (i) lateral to C6/7 on the affected side and (ii) over Erb's point on the affected side. The former electrode position represents an attempt to provide TENS stimulation to the dermatone served by C6/7 which is in the lateral and distal aspect of the arm. The latter electrode position, on the other hand, is designed to stimulate the nerve course of the brachial plexus at a position where it is relatively superficial to the skin surface. The rationale for selecting these placements, as outlined at the end of the review of literature (see Section 7.4), was based on their use in previous TENS studies which have used the ischaemic pain model (Foster et al, 1995; Walsh et al, 1993; Walsh et al, 1995).

As already mentioned in Section 15.2, a possible problem with the tourniquet method of experimental ischaemic pain induction is the sensory disturbance to the nerves in the arm distal to the cuff and this is a potential source of error in the experimental ischaemic pain study carried out by Roche et al (1984) (see Section 6.5). The possible influence of nerve compression on nerve function results in electrode positioning at the site of pain being unsuitable with this model of experimental pain induction. In the clinical situation it is advantageous to position the electrodes close to the site of pain so as to ensure that the TENS stimulation is entering the same spinal levels as the original pain. In the present study it should be stressed that both the electrode placed lateral to C6/7 and the electrode over Erb's point were theoretically stimulating the same spinal segment in the arm as the ischaemic pain and were, therefore, positioned appropriately. In future experimental ischaemic pain studies it is necessary to address ideal electrode placement, taking into consideration the issue of nerve compression by the cuff. What does appear to be advantageous with this particular pain model is that the electrodes are positioned proximal, and not distal, to the cuff.

15.7 : Implications for clinical practice and possibilities for future research

Other issues which have been raised in the present study and that have important implications for the use of TENS in the clinical setting include the need for clinical pain reports, based on neurophysiological evidence, to state clearly what patient group is being treating (acute or chronic pain), what parameters of TENS are being used (frequency, intensity, pulse duration, waveform, electrode placement, treatment duration) and under what conditions they are applied (location,

operator). The findings of the present study have indicated that subjects gave lower ratings of pain whilst receiving TENS stimulation and that the efficacy of the treatment was further enhanced when the subject, and not the experimenter, controlled the current intensity. It therefore seems appropriate for clinical pain reports to clearly state who controls the TENS stimulus during treatment.

The present study has also addressed the importance of pain assessment procedure on pain outcomes and has identified the need for careful consideration of choice of measurement tools. The components of the pain response being assessed at either 1st or 2nd stage of pain perception should be distinguishable, should be assessed separately and should be specific to the type of pain being assessed (e.g. 2nd stage pain perception with chronic pain).

The results of the present study suggested that subject control of the current intensity was most beneficial when the mean pain scores given by subjects in the two TENS conditions (subject and experimenter control) were significantly lower than the mean pain scores given by the condition receiving no TENS at all. In the present study TENS was more effective in relieving pain than the no treatment condition when a low frequency (5Hz) current was employed. In the case of the high frequency (100Hz) TENS the modality, under subject or experimenter control, was no more effective in relieving pain than no TENS. It presents, therefore, that only when TENS was found to be more effective in relieving pain than no TENS that subject control was an enhancing factor.

It could therefore be argued that pain-relief with TENS would be optimised if subjects were allowed to select all their preferred TENS parameters (e.g. frequency, intensity, pulse duration, waveform, electrode placement) as in the studies carried out by Johnson et al (1991a and 1991b). In this way subjects would be able to control their own treatment with TENS using the parameters which they found most beneficial in relieving their pain. It is suggested that clinical TENS trials evaluating the effects of TENS should use the modality in the manner which it is most commonly used in the clinical setting. For example, patients receiving TENS treatment for chronic pain should be given the modality for everyday prolonged use as opposed to 20 minute treatment sessions 3 times a week. This is not to say that all TENS studies should be carried out in this manner, such as experimental studies which attempt to tightly control variables, but all those that aim to investigate clinical efficacy.

Future work to be carried out in this research area should include the investigation of how the variable of control affects other models of experimental pain and also clinical pain. Taking into account the possible limitations of the ischaemic model of pain induction used in the present study, it appears beneficial to carry out similar studies under tightly controlled experimental conditions. It would then be useful to progress onto clinical studies investigating the effect of control on pain-relief using TENS. Second stage pain perception could be assessed, as well as first stage, in order to investigate the long-term influences of TENS on pain and daily functioning. This would provide valuable information as to how TENS can help in the management of chronic pain conditions but caution will be needed in the

interpretation of the results when attributing the outcomes to other external variables. The present study used a transient form of experimental pain and therefore it was thought more appropriate to measure pain *during* pain induction. The pain-relieving action of TENS, regardless of the parameters used, is relatively short-lasting once the current stimulus is removed (Eriksson et al, 1979; Sjolund and Eriksson, 1979). The results of the present study also supported the evidence that TENS provides a distraction from the original pain and indicated that TENS is most effective in relieving pain when the current is actually operational. It therefore appears more beneficial for patients in clinical TENS studies to rate their pain or related function whilst the modality is *in situ*. Take, for example, a person's pain being assessed at regular intervals after they had received oral analgesia. What the outcome measures would be providing information about is the duration and quality of pain-relief that the drug was providing. In the same way, assessing a person's pain once TENS has been removed provides information about how long pain-relief is achieved, and to what extent, once the stimulus is no longer present. Pain assessment after TENS has been removed, therefore, is useful to give guidelines as to how regularly treatment should be given and identify mechanisms of action but does not directly reflect how TENS influences a person's pain whilst in operation. This is not to say that pain measures should only be taken *during* TENS treatment but that for all types of TENS study, the experimenter must decide the measurement tool and timing of that tool which provides most meaningful results.

The present study was investigating the difference between subject and experimenter control of the TENS current intensity and therefore was not concerned with the degree of the perceived degree of control that the subject believed they had over their treatment. Perceived Locus of Control (PLOC) scales are often used in studies involving control (see Section 5.5) and it would be useful to monitor this perception of control during further studies. It would also be interesting to see further work being carried out, using a similar approach to the present study, to establish the effect of other TENS parameters such as current intensity or pulse duration on pain perception as these are features which contribute to the qualitative nature of the TENS stimulus. In this way the parameters of TENS could be altered to increase the clinical relevance of the results. Ultimately, any further work into control and TENS should identify factors involved in the application of the modality which can then be manipulated to optimise pain-relief for its users.

15.8 : Conclusions

(1) Greatest pain-relief with TENS was achieved in the present study when the subject controlled the current intensity and a low frequency (5Hz) current was used. The results of experiment 5 found that mean pain scores were statistically significantly lower in the subject controlling TENS condition than in either the experimenter controlling TENS condition or the no TENS condition (intensity $F=3.76$; d.f.=28,308; $p<0.001$: unpleasantness $F=3.33$; d.f.=28,308; $p<0.001$). The results of experiment 6 found a statistical trend which indicated that the pain-

relieving effect of the low frequency current was repeatable at p values of 0.239 (intensity) and 0.110 (unpleasantness).

(2) Subject control of the current intensity was found to be more effective than experimenter control in the present study when subjects in both the two TENS conditions (experimenter and subject control) gave lower mean pain scores than the no TENS condition (i.e. TENS was found to be more effective than no TENS). The result suggested that optimal pain-relief with TENS is most likely to be achieved when patients are allowed to select their own preferred parameters.

(3) The ischaemic model of experimental pain induction is responsive to testing the efficacy of TENS. This was indicated graphically by the gradual increase in mean pain scores rated by the subjects during the pain induction procedures in each experiment and reflected by the significant F values in the 'time' condition calculated in the respective ANOVAs.

(4) TENS independently influences VAS measures of both present pain intensity and present pain unpleasantness. This was indicated by the difference in variance of scores given for the two pain components and supported by the questionnaire responses in experiments 2 and 6.

(5) The present study highlighted the need for pain studies to distinguish between 1st and 2nd stage pain perception and assess separately the sensory-discriminative, motivational-affective and cognitive-evaluative components of the pain response. This is based on the differences noted in the present study between the variance of pain intensity and pain unpleasantness scores.

REFERENCES

REFERENCES

Anton, F., Euchner, I. and Handwerker, H.O. (1992) Psychophysical examination of pain induced by defined carbon dioxide pulses applied to the nasal mucosa. **Pain, 49;** p53-60.

Arendt-Nielsen, L., Zacharie, R. and Bjerring, P. (1990) Quantitative evaluation of hypnotically suggested hyperaesthesia and analgesia by painful laser stimulation. **Pain, 42;** p243-251.

Baker, L.L., Bowman, B.R. and McNeaL, D.R. (1988) Effects of waveform on comfort during neuromuscular electrical stimulation. **Clinical Orthopaedics and Related Research, 233;** p75-85.

Beecher, H.K.. (1955) The powerful placebo. **Journal of the American Medical Association, 159;** p1602-1606.

Basbaum, A.I. and Fields, H.L. (1978) Endogenous pain control mechanisms. Review and hypothesis. **Annals of Neurology, 4;** p451-462.

Belanger, A.Y. (1985) Physiological evidence for an endogenous opiate-related pain-modulating system and its relevance to TENS: A review. **Physiotherapy Canada, 37(3);** p163-168.

Bond, M.R. (1984) **Pain. Its nature, analysis and treatment (2nd Edition).** Churchill Livingstone. Edinburgh.

Brennum, J., Kjeldsen, M. and Jensen, T.S. (1989) Measurement of human pressure-pain thresholds on fingers and toes. **Pain, 38;** p211-217.

Brevik, E.K., Haanaes, H.R. and Skoglund, L.A. (1996) Pain intensity assessments on horizontal compared with vertical visual analogue scales (VAS). **Poster presentation at 8th World Congress on Pain.** Vancouver. August 1996.

Bromm, B. (1984) **Pain measurement in man: Neurophysiological correlates of pain.** Elsevier Science Publishers. Amsterdam

Cailliet, M.D. (1993) **Pain: Mechanisms and management.** F.A.Davis Company. Philadelphia.

Campbell, J.N. and Taub, A. (1973) Local analgesia from percutaneous electrical stimulation. **Archives of Neurology, 28;** p347-350.

Carroll, D., Tramer, M., McQuay, H., Nye, B. and Moore, A. (1996) Randomisation is important in studies with pain outcomes: systematic review of transcutaneous electrical nerve stimulation in acute postoperative pain. **British Journal of Anaesthesia, 77;** p798-803.

Carroll, D., Tramer, M., McQuay, H., Nye, B. and Moore, A. (1997) Transcutaneous electrical nervestimulation in labour pain: a systematic review. **British Journal of Obstetrics and Gynaecology, 104;** p169-175.

Cervero, F. (1986) Neurophysiological aspects of pain and pain therapy. In **The Therapy of Pain (2nd Edition).** Edited by Swerdlow, M. M.T.P. Press Limited. Lancaster.

Chapman, C.R., Casey, K.L., Dubner, R., Foley, K.M., Gracely, R.H. and Reading, A.E. (1985) Pain measurement : An overview. **Pain, 22;** p1-31.

Charman, R.A. (1989) Pain theory and physiotherapy. **Physiotherapy, 75(5);** p247-254.

Chen, A.C.N., Dworkin, J.H. and Gehrig, J. (1989) Human pain responsitivity in a tonic pain model: Psychological determinants. **Pain, 37;** p143-160.

Clancey, J, and McVicar, A. (1992) Subjectivity of pain. **British Journal of Nursing, 1(1);** p8-12.

Conn, G., Marshall, A., Yadav, S., Daly, J.C. and Jaffer, M. (1986) Transcutaneous electrical nerve stimulation following appendectomy: the placebo effect. **Annals of the Royal College of Surgeons of England, 68;** p191-192.

Cuschieri, R.J., Morran, C.G. and McArdle, C.S. (1985) Transcutaneous electrical stimulation for postoperative pain. **Annals of the Royal College of Surgeons of England, 67;** p127-129.

Delitto, A. and Rose, S.J. (1986) Comparative comfort of three waveforms used in electrically eliciting quadriceps femoris muscle contractions. **Physical Therapy, 66(11);** p1704-1707.

Deyo, R.A., Walsh, N.E., Martin, D.C., Schoenfeld, L.S. and Ramamurthy, S. (1990) A controlled trial of transcutaneous electrical nerve stimulation (TENS) and exercise for chronic low back pain. **New England Journal of Medicine, 322(23);** p1627-1634.

Duncan, G.H., Bushnell, C. and Lavigne, G.J. (1989) Comparison of verbal and visual analogue scales for measuring the intensity and unpleasantness of experimental pain. **Pain, 37;** p295-303.

Duncan, G.H., Duquette, P. and Bushnell, C. (1985) Measurement of the intensity and unpleasantness of pain in French Canadians. **Journal of Dental Research, 64;** p271.

Ellis, B. (1995) Transcutaneous electrical nerve stimulators: Outpatient response to a temporary home-loan programme. **British Journal of Therapy and Rehabilitation, 2(8);** p419-423.

Eriksson, M.B.E., Sjolund, B.H. and Nielzen, S. (1979) Long term results of peripheral conditioning stimulation as an analgesic measure in chronic pain. **Pain, 6;** p335-347.

Ernst, E. and Resch, K.L. (1996) The clinical trial - gold standard or naive reductionism? **European Journal of Medicine and Rehabilitation, 6(1);** p26-27.

Fields, H.L. (1987) **Pain.** McGraw-Hill Inc. New York.

Fernandez, E. and Towery, S. (1996) A parsimonious set of descriptors of pain sensation derived from the McGill Pain Questionnaire. **Pain, 66;** p31-37.

Foster, N.E., Walsh, D.M., Baxter, G.D. and Allen, J.M. (1995) An investigation of the hypoalgesic effects of combinations of transcutaneous electrical nerve stimulation (TENS) parameters upon experimentally induced ischaemic pain (abstract). **Proceedings of the 1995 World Congress of Physiotherapy.**

Garrison, D.W. and Foreman, R.D. (1994) Decreased activity of spontaneous and noxiously evoked dorsal horn cells during transcutaneous electrical nerve stimulation (TENS). **Pain, 58;** p309-315.

Gielen, F. (1989) Discussion of placebo effect in physiotherapy based on a noncritical review of the literature. **Physiotherapy Canada, 41(4);** p210-215.

Gracely, R.H. (1994) Studies of pain in normal man. In **Textbook of Pain (3rd Edition).** Edited by Wall, P.D.and Melzack, R. Churchill Livingstone. Edinburgh.

Gracely, R.H., Dubner, R. and McGrath, P.A. (1979) Narcotic analgesia : fentanyl reduces the intensity but not the unpleasantness of painful tooth pulp sensations. **Science, 203;** p1361-1379.

Gracely, R.H., McGrath, P.A. and Dubner, R. (1978) Ratio scales of sensory and affective verbal pain descriptors. **Pain, 5;** p5-18.

Grimby, G. and Wigerstad-Lossing, I. (1989) Comparison of high and low frequency muscle stimulators. **Archives of Physical and Medical Rehabilitation, 70;** p835-838.

Guilbaud, G., Bernard, J.F. and Besson, J.-M. (1994) Brain areas involved in nociception and pain. In **The Textbook of Pain (3rd Edition).** Edited by Wall, P.D. and Melzack, R. Churchill Livingstone.

Guyton, A.C. (1991) **Textbook of Medical Physiology (8th Edition).** W.B. Saunders Company .Philadelphia.

Handwerker, H.O., Iggo, A. and Zimmermann, M. (1975) Segmental and supraspinal actions on dorsal horn neurones responding to noxious and non-noxious skin stimuli. **Pain, 1;** p142-165.

Handwerker, H.O. and Kobal, G. (1993) Psychophysiology of experimentally induced pain. **Physiological Reviews, Vol 73(3);** p639-671.

Heath, M.L. and Thomas, V.J. (1993) **Patient-controlled analgesia. Confidence in postoperative pain control.** Oxford University Press. Oxford.

Howson, D.C. (1978) Peripheral neural excitability. Implications for transcutaneous nerve stimulation. **Physical Therapy, 58(12);** p1467-1473.

Hughes, G.S., Lichstein, P.R., Whitlock, D. and Harker, C. (1984) Response of plasma beta endorphins to transcutaneous electrical nerve stimulation in healthy subjects. **Physical Therapy, 64(7);** p1062-1066.

Humphries, S.A., Long, N.R. and Johnson, M.H. (1994) Ionophoretically applied potassium ions as an experimental pain stimulus for investigating pain mechanisms. **Perception and Psychophysics, 56(6);** 637-648.

Ignelzi, R.S. and Nyquist, J.K. (1976) Excitability changes in peripheral nerve fibres after repetitive electrical stimulation. **Journal of Neurosurgery, 51;** p824-833.

Janssen, S.A. and Arntz, A. (1996) Anxiety and pain : attentional and endorphinergenic influences. **Pain, 66;** p145-150.

Jensen, M.P. and Karoly, P (1992) Self-report scales and procedures for assessing pain in adults. In **Handbook of Pain Assessment.** Edited by Turk, D.C. and Melzack, R. The Guilford Press. New York.

Jensen, M.P., Karoly, P. and Braver, S. (1986) The measurement of clinical pain intensity : A comparison of six methods. **Pain, 27;** p117-126.

Jensen, R., Rasmussen, B.K., Pederson, B., Lous, I. and Olesen, J. (1992) Cephalic muscle tenderness and pressure pain threshold in a general population. **Pain, 48;** p197-203.

Jessell, T.M. and Kelly, D.D. (1991) Pain and Analgesia. In **Principles of Neural Science (3rd Edition).** Edited by Kandel, E.R., Schwartz, J.H. and Jessel, T.M. Prentice-Hall International Inc. London.

Jette, D.U. (1986) Effect of different forms of transcutaneous electrical nerve stimulation on experimental pain. **Phyical Therapy, 66(2);** p187-19.

Johnson, M.I. (1997) The physiology of the sensory dimensions of clinical pain. **Physiotherapy, 83(10);** p526-536.

Johnson, M.I., Ashton, C.H., Bousfield, D.R. and Thompson, J.W. (1989) Analgesic effects of different frequencies of transcutaneous electrical nerve stimulation on cold-induced pain in normal subjects. **Pain, 39;** p231-236.

Johnson, M.I., Ashton, C.H. and Thompson, J.W. (1991a) An in-depth study of long-term users of transcutaneous electrical nerve stimulation (TENS). Implications for clinical use of TENS. **Pain, 44;** p221-229.

Johnson, M.I., Ashton, C.H. and Thompson, J.W. (1991b) The consistency of pulse frequencies and pulse patterns of transcutaneous electrical nerve stimulation (TENS) used by chronic pain patients. **Pain, 44;** p231-234.

Johnson, M.I., Ashton, C.H. and Thompson, J.W. (1993) A prospective investigation into factors related to patient response to transcutaneous electrical nerve stimulation (TENS) - the importance of cortical responsitivity. **European Journal of Pain, 14,** p1-9.

Jones, A.K.P. (1997) Pain, its perception, and pain imaging. **I.A.S.P. Newsletter, May / June;** p3-5.

Jones, A.Y.M., Lee, R., Holzberger, D. and Jones, R.D.M. (1990) A comparison of different electrode placements on the effectiveness of TENS in pain relief for post-cholecystectomy patients. **Physiotherapy, 76(9);** p567-570.

Kahn, J. (1994) **Principles and Practice of Electrotherapy (3rd Edition).** Churchill Livingstone. London.

Kane, K. and Taub, A. (1975) A history of local electrical analgesia. **Pain, 1;** p125-138.

Kanfer, F.H. and Seidner, M.L. (1973) Self-control: Factors enhancing tolerance of noxious stimulation. **Journal of Personality and Social Psychology, 18(2);** p157-162.

Keele, C.A. and Neil, E. (1965) **Samson Wright's Applied Physiology (Eleventh Edition).** Oxford University Press. London.

Klaber Moffett, J.A. and Richardson, P.H. (1997) The influence of the physiotherapist-patient relationship on pain and disability. **Physiotherapy Theory and Practice, 13;** p89-96.

Leavitt, F., Garron, D.C., Whisler, W.W. and Sheinkop, M.B. (1978) Affective and sensory dimensions of back pain. **Pain, 4;** p273-281.

Le Bars, D., Dickenson, A.H., and Besson, J.-M. (1979) Diffuse noxious inhibitory controls (DNIC). Effects on dorsal horn convergent neurones in the rat. **Pain, 6;** p283-304.

Lehmann, T.R., Russell, D.W., Spratt, K.F., Colby, H., Liu, Y.K., Fairchild, M.L. and Christensen, S. (1986) Efficacy of electroacupuncture and TENS in the rehabilitation of chronic low back pain patients. **Pain, 26;** p277-290.

Levin, M.F. and Hui-Chan, C.W.Y. (1993) Conventional and acupuncture-like transcutaneous electrical nerve stimulation excite similar afferent fibres. **Archives of Physical and Medical Rehabilitation, 74;** p54-60.

Levine, J.D., Gordon, N.C. and Fields, H.L. (1978) The mechanism of placebo analgesia. **Lancet, 2;** p654-657.

Lima, D. (1997) Functional anatomy of spinofugal nociceptive pathways. **Pain Reviews, 4;** p1-19.

Low, J. and Reed, A. (1990) **Electrotherapy explained. Principles and Practice.** Butterworth Heinemann. London.

Mannheimer, J.S. (1985) TENS: uses and effectiveness. In **Pain.** Edited by Theresa Hoskins Michel. Churchill Livingstone.

Mannheimer, J.S. and Lampe, G.N. (1984) **Clinical transcutaneous electrical nerve stimulation.** F.A. Davis. Philadelphia.

Marchand, S., Charest, J., Li, J., Chenard, J., Lavignolle, B. and Laurencelle, L. (1993) Is TENS purely a placebo effect? A controlled study on chronic low back pain. **Pain, 54;** p99-106.

McDowell, B.C., Lowe, A.S., Walsh, D.M., Baxter, G.D. and Allen, J.M. (1995) The lack of hypoalgesic effect of H-wave therapy on experimental ischaemic pain. **Pain, 61;** p27-32.

McQuay, H., Carroll, D. and Moore, A. (1995) Variation in the placebo effect in randomised controlled trials of analgesics : all is as blind as it seems. **Pain, 64;** p331-335.

Melzack, R. (1975) The McGill Pain Questionnaire : Major properties and scoring methods. **Pain, 1;** p277-299.

Melzack, R. and Casey, K.L (1968) Sensory, motivational and central control determinants of pain. In **The skin senses.** Edited by Kenshalo, D.R. and Thomas, C.C. Springfield.

Melzack, R. and Katz, J. (1992) The McGill Pain Questionnaire: Appraisal and current status. In **Handbook of Pain Assessment.** Edited by Turk, D.C. and Melzack, R. The Guilford Press. New York.

Melzack, R. and Wall, P.D. (1965) Pain mechanisms. A new theory. **Science, 150;** p971-979.

Merskey, H. (1974) Assessment of Pain. **Physiotherapy, 60(4);** p96-98.

Merskey, H. (1979) Pain terms: A list with definitions and notes on usage. **Pain, 6;** p249-252.

Meyer, R.A., Campbell, J.N. and Raja, S.N. (1994) Peripheral neural mechanisms of nociception. In **The Textbook of Pain (3rd Edition).** Edited by Wall, P.D. and Melzack, R. Churchill Livingstone. Edinburgh.

Meyer, G.A. and Fields, H.L. (1972) Causalgia treated by selective large fibre stimulation of peripheral nerve. **Brain, 95;** p163-168.

Miron, D., Duncan, G.H. and Bushnell, M.C. (1989) Effects of attention on the intensity and unpleasantness of thermal pain. **Pain, 39;** p345-352.

Moore, J.D., Weissman, L., Thomas, G. and Whitman, E.N. (1971) Response of experimental ischaemic pain to analgesics in prisoner volunteers. **Journal of Clinical Pharmacology, 11;** p433-439.

New Shorter Oxford English Dictionary (October 1993) Edited by Brown, L. Oxford University Press. Oxford.

O'Brien, W.J., Rutan, F.M., Sanborn, C. and Omer, G.E. (1984) Effect of transcutaneous electrical nerve stimulation on human blood beta-endorphin levels. **Physical Therapy, 64(9);** p1367-1374.

Ohnhaus, E.E. and Adler, R. (1975) Methodological problems in the measurement of pain: A comparison between the verbal rating scale and the visual analogue scale. **Pain, 1;** p379-384.

Payton, O.D. (1994) **Research: The validation of clinical practice (3rd Edition).** F.A. Davis Company. Philadelphia.

Pertovaara, A., Nurmikko, T. and Pontinen, P.J. (1984) Two separate components of pain produced by the submaximal effort tourniquet test. **Pain, 20;** p53-58.

Pervin, L.A. (1963) The need to predict and control under conditions of threat. **Journal of Personality and Social Psychology, 31;** p570-587.

Philips, D.S. (1978) **Basic statistics for health science students.** W.H. Freeman and Company. San Francisco.

Pope, G.D., Mockett, S.P. and Wright, J.P. (1995) A survey of electrotherapeutic modalities: ownership and use in the NHS in England. **Physiotherapy, 81;** p82-91.

Posner, J. (1984) A modified submaximal effort tourniquet test for evaluation of analgesics in healthy volunteers. **Pain, 19;** p143-151.

Price, D.D. and Harkins, S.W. (1992) Psychological approaches to pain measurement and assessment. In **Handbook of Pain Assessment.** Edited by Turk, D.C. and Melzack, R. The Guilford Press. New York.

Price, D.D., Harkins, S.W. and Baker, C. (1987) Sensory-affective relationships among different types of clinical and experimental pain. **Pain, 28;** p297-307.

Price, D.D., McGrath, P.A., Rafii, A. and Buckingham, B. (1983) The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. **Pain 17;** p 45-56.

Price, D.D., Von der Gruen, A., Miller, J., Rafii, A. and Price, C. (1985) Apsychophysical analysis of morphine analgesia. **Pain, 22;** p261-269.

Procacci, P., Zoppi, M. and Maresca, M. (1979) Experimental pain in man. **Pain, 6;** p123-140.

Richardson, P.H. (1994) Placebo effects in pain management. **Pain Reviews, 1;** p15-32.

Robinson, A.J. (1996) Transcutaneous electrical nerve stimulation for the control of pain in musculoskeletal disorders. **Journal of Sport and Physical Therapy, 24(4);** p298-226.

Roche, P.A., Gjisbers, K., Belch, J.J.F. and Forbes, C.D. (1984) Modification of induced ischaemic pain by TENS. **Pain 7;** p45-52.

Roche, P.A. and Gijsbers, K. (1986) A comparison of memory for induced ischaemic pain and chronic rheumatoid pain. **Pain, 25;** p337-343.

Scott, O. (1994) Sensory and motor nerve activation. In **Glayton's Electrotherapy (9th Ed.).** Edited by Kitchen, S. and Bazin, S. WB Saunders Company Ltd. London.

Sjolund, B.H. and Eriksson, M.B.E. (1979) The influence of naloxone on analgesia produced by peripheral conditioning stimulation. **Brain Research, 173;** p295-301.

Smith, G.M., Egbert, L.D., Markowitz, R.A., Mosteller, F. and Beecher, H.K. (1966) An experimental pain method sensitive to morphine in man: the submaximum effort tourniquet technique. **Jounal of Pharmacy and Experimental Therapy, 154(2);** p324-332.

Sriwatanakul, K., Kelvie, W., Lasagna, L., Calimlim, J.F., Weis, O.F. and Mehta, G. (1983) Studies with different types of visual analogue scales for measurement of pain. **Clinical Pharmacology and Therapy, 34(2);** p234-239.

Staub E., Turskey, B. and Schwartz, G.E. (1971) Self-control and predictability: Their effects on reactions to aversive stimulation. **Journal of Personality and Social Psychology, 18(2);** p157-162.

Steedman, W.M. (1989) The influence of cutaneous inputs on the activity of neurones in the substantia gelatinosa. In **Processing of sensory information in the superficial dorsal horn of the spinal cord.** Edited by Cervero, F., Bennett, G.J. and Headley, P.M. Plenum Publishing Corporation. New York.

Steedman, W.M. and Malony, V. (1987) Intracellularly recorded responses in neurones in Lamina II of cat spinal dorsal horn to activation of cutaneous afferent inputs. In **Fine afferent nerve fibres and pain.** Edited by Schmidt, R.F., Schaible, H.-G. and Vahle-Hinz, C. V.C.H. Weinheim

Swett, J.E. and Law, J.D. (1983) Analgesia with peripheral nerve stimulation : Absence of a peripheral mechanism. **Pain, 15;** p55-70.

Thomas, V., Heath, M., Rose D. and Flory, P. (1995) Psychological characterististics and the effectiveness of patient-controlled analgesia. **British Journal of Anaesthesia, 74;** p271-276.

Thompson, J.W. (1988) Pharmacology of transcutaneous electrical nerve stimulation (TENS). **Intractable Pain Society, 7(1);** p33-39.

Thompson, S.C. (1981) Will it hurt less if I can control it? A complex answer to a simple question. **Psychology Bulletin, 90(1);** p89-101.

Toomey, T.C., Mann, J.D., Abashian, S. and Thompson-Pope, S. (1991) Relationship between perceived self-control of pain, pain description and functioning. **Pain 45;** p129-133.

Torebjork, H.E. and Hallin, R.G. (1973) Perceptual changes accompanying controlled preferential blocking of A and C fibre responses in intact human skin nerves. **Experimental Brain Research, 16;** p321-322.

Torebjork, H.E. and Hallin, R.G. (1974) Methods to differentiate electrically induced afferent and sympathetic C unit responses in human cutaneous nerves. **Acta. Physiol. Scand., 92;** p318-331.

Turner, J.A., Deyo, R.A., Loeser, J.D., Von Korff, M. and Fordyce, W.E. (1994) The importance of placebo effects in pain treatment and research. **Journal of the American Medical Association, 271(20);** p1609-1614.

Veerasarn, P. and Stohler, C.S. (1992) The effect of experimental muscle pain on the background electrical brain activity. **Pain, 49;** 349-360.

Wade, J.B., Dougherty, L.M., Archer, C.R. and Price, D.D. (1996) Assessing the stages of pain processing: a multivariate analytical approach. **Pain, 68;** p157-167.

Wall, P.D. (1992) The placebo effect : an unpopular topic. **Pain, 51;** p1-3.

Walsh, D.M. (1991) Nociceptive pathways - relevance to the physiotherapist. **Physiotherapy, 77(5);** p317-321.

Walsh, D.M. (1997) **TENS : Clinical application and related theory.** Churchill Livingstone. New York.

Walsh, D.M., Liggett, C., Baxter, G.D. and Allen, J.M. (1993) A comparative study of the hypoalgesic effects of TENS and H-wave therapy upon experimentally induced ischaemic pain (abstract). **Proceedings of the 7th World Congress on Pain.**

Walsh, D.M., Liggett, C., Baxter, G.D. and Allen, J.M. (1995) A double-blind investigation of the hypoalgesic effects of TENS upon experimentally induced ischaemic pain. **Pain 61;** p39-45.

Ward, L., Wright, E. and McMahon, B. (1996) A comparison of the effects of noxious and innocuous counterstimuli on experimentally induced pain and itch. **Pain, 64;** p129-138.

Waterfield, J. and Sim, J. (1996) Clinical assessment of pain by the visual analogue scale. **British Journal of Therapy and Rehabilitation, 3(12);** p94-97.

Watson, J. (1982) Pain .Mechanisms - a review III Endogenous pain control mechanisms. **Australian Journal of Physiotherapy, 28(2);** p38-45.

Weisenberg, M. (1994) Cognitive aspects of pain. In **The Textbook of Pain (3rd Edition).** Edited by Wall, P.D. and Melzack, R. Churchill Livingstone. Edinburgh.

Weisenberg, M., Wolf, Y., Mittwoch, T., Mikulincer, M. and Aviram, O. (1985) Subject versus experimenter control in the reaction to pain. **Pain 23;** p187-200.

Widerstrom, E.G., Aslund, P.G., Gustafsson, L.E., Mannheimer, C., Carlsson, S.G. and Andersson, S.A. (1992) Relations between experimentally induced tooth pain threshold changes, psychometerics and clinical pain relief following TENS. A retrospective study in patients with long-lasting pain. **Pain, 51;** p281-287.

Wiedenfield, S.A., O'Leary, A., Bandura, A., Brown, S., Levine, S. and Raska, K. (1990) Impact of perceived self-efficacy in coping with stressors on components of the immune system. **Journal of Personality and Social Psychology, 59;** p1082-1094.

Winer, B.J., Brown, D.R. and Michels, K.M. (1991). **Statistical Principles in Experimental Design (3rd Edition).** McGraw-Hill Book Company, New York, London.

Wolf, S.L., Gersh, M.R. and Rao, V.R. (1981) Examination of electrode placements and stimulating parameters in treating chronic pain with conventional transcutaneous electrical nerve stimulation (TENS). **Pain;** p37-47.

Woolf, C.J. (1979) TENS and the reaction to experimental pain in human subjects. **Pain 7;** p115-127.

Woolf, C.J. and Thompson, J.W. (1994) Stimulation fibre-induced stimulation: transcutaneous electrical nerve stimulation (TENS) and vibration. In **The Textbook of Pain (3rd Edition).** Edited by Wall, P.D. and Melzack, R. Churchill Livingstone. Edinburgh.

Wright, A. (1995) Hypoalgesia post-manipulative therapy: a review of a potential neurophysiological mechanism. **Manual Therapy,1;** p11-16.

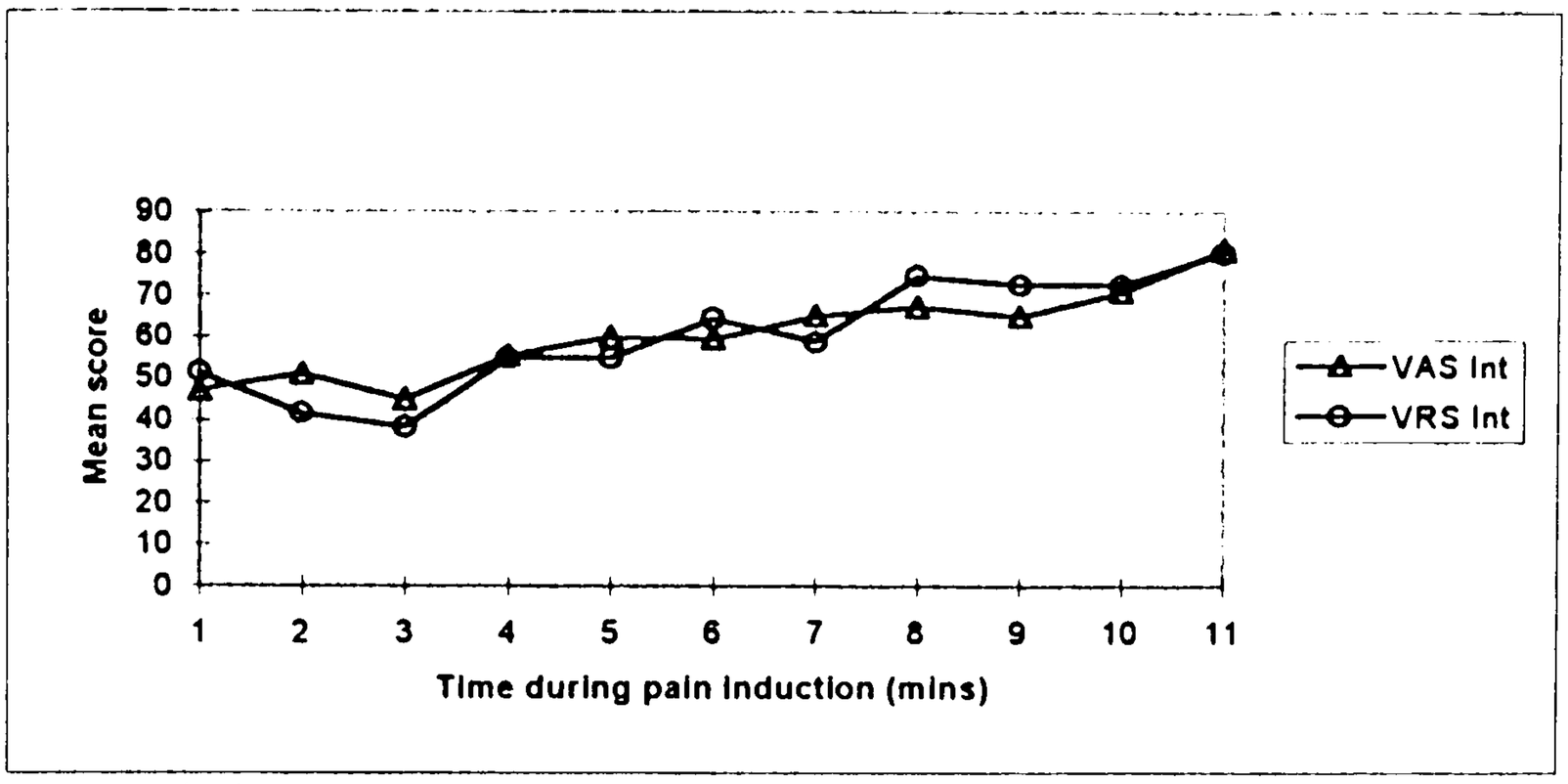
Wright, A. and Davies, I.I. (1989) The recording of brain evoked potentials resulting from intra-articular focused ultrasonic stimulation: a new experimental model for investigating joint pain in humans. **Neuroscience Letters, 97;** p145-150.

Yamada, T., Muroga, T. and Kimura, J. (1981) Tourniquet-induced ischaemia and somatosensory evoked potentials. **Neurology, 31;** p1524-1529.

APPENDICES

Appendix 1 : Experiment 1 - Graphs and Tables

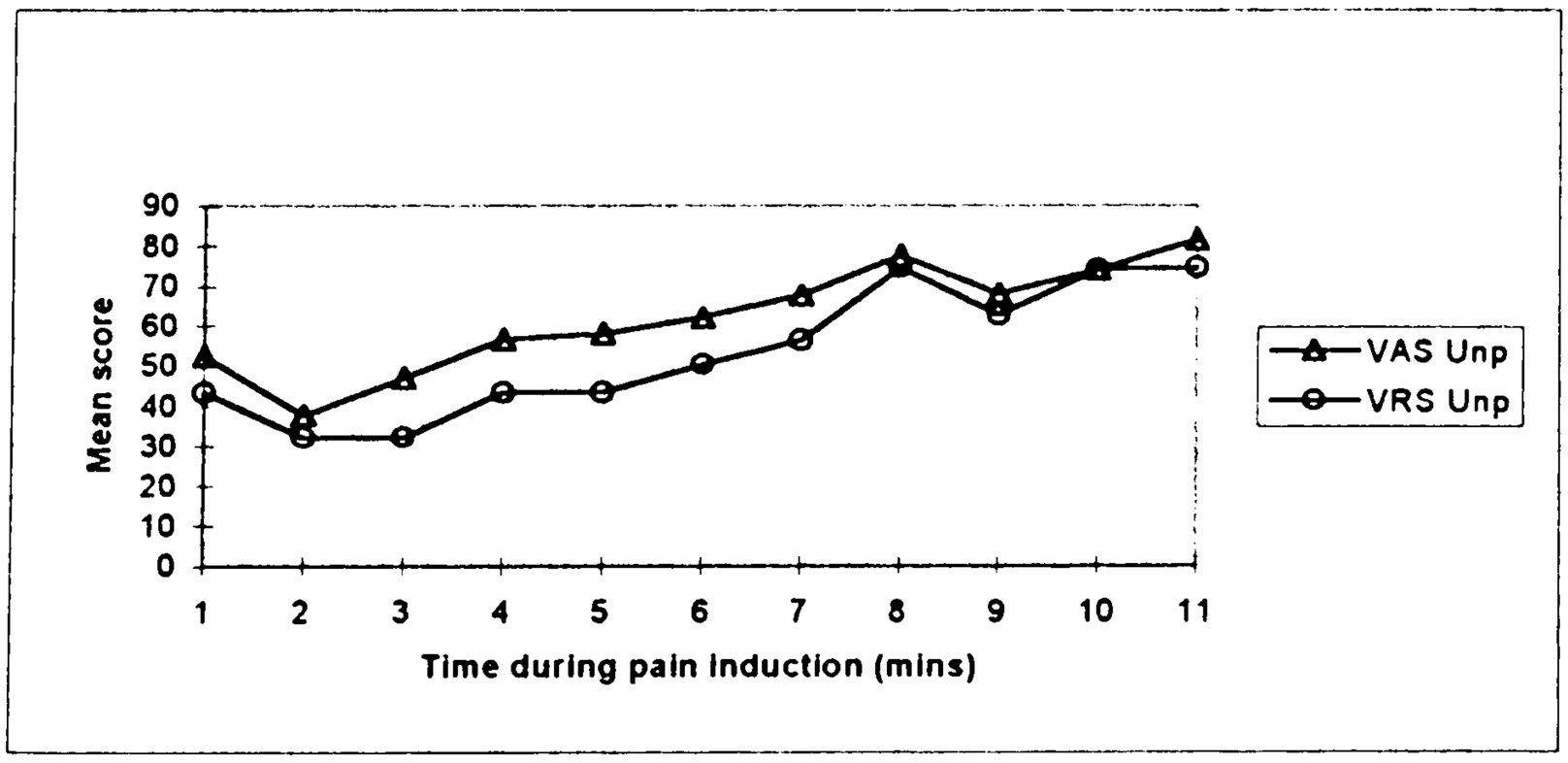
Figure I : Mean VAS and VRS pain intensity scores during pain induction



N.B. It is important to note that due to the drop-out rate in this experiment that the number of subjects at all of the minute pain assessment intervals is not the same. The actual number of subjects at each time point is indicated by the 'n' numbers listed in the table below.

Time (mins)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
n	12	12	10	10	10	10	9	9	6	6	2

Figure II : Mean VAS and VRS pain unpleasantness scores during pain induction



N.B. It is important to note that due to the drop-out rate in this experiment that the number of subjects at all of the minute pain assessment intervals is not the same.The actual number of subjects at each time point is indicated by the 'n' numbers listed in the table below.

Time (mins)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
n	12	12	10	10	10	10	9	9	6	6	2

Figure III : Correlation of mean VAS and VRS pain intensity scores

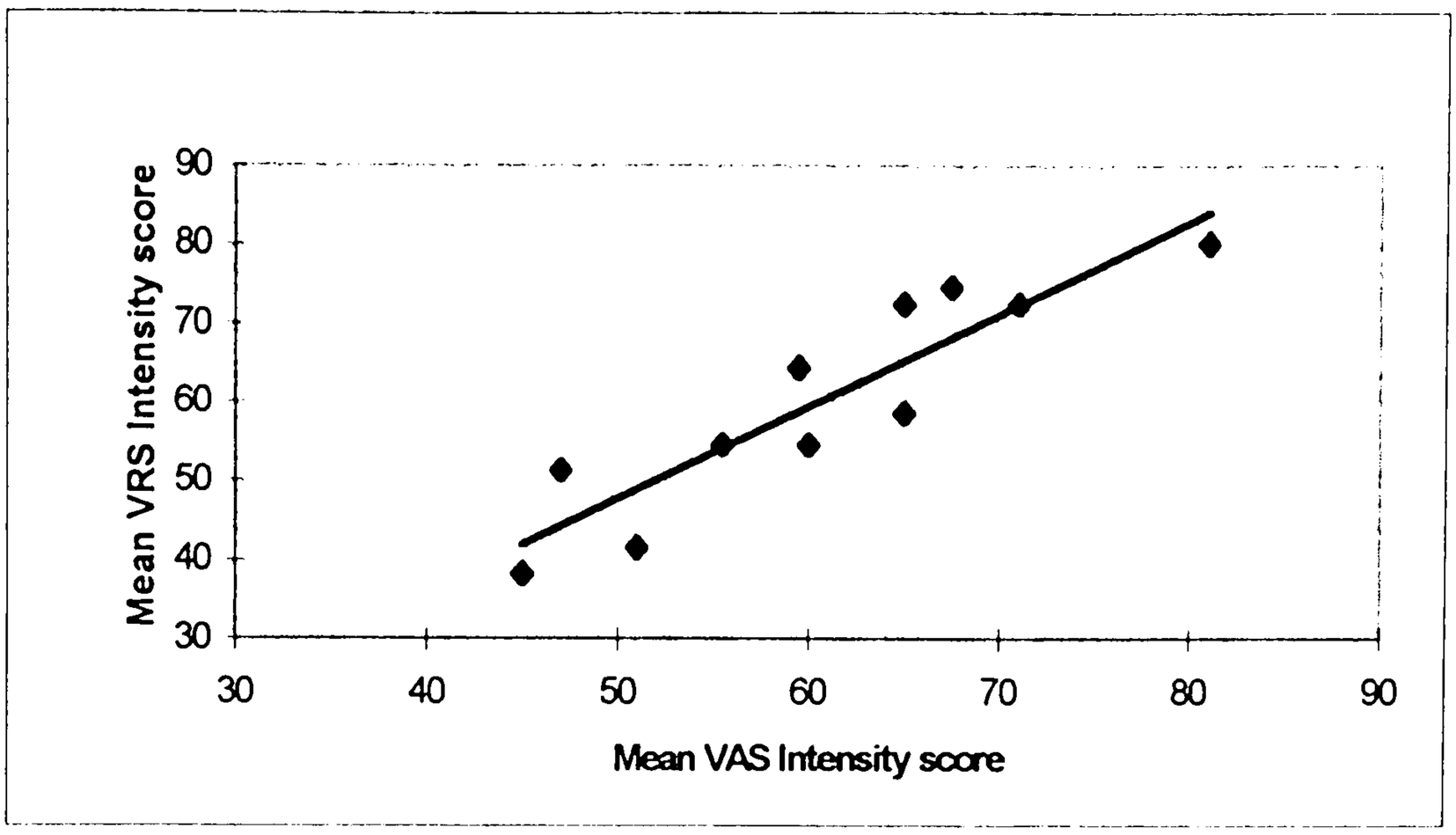
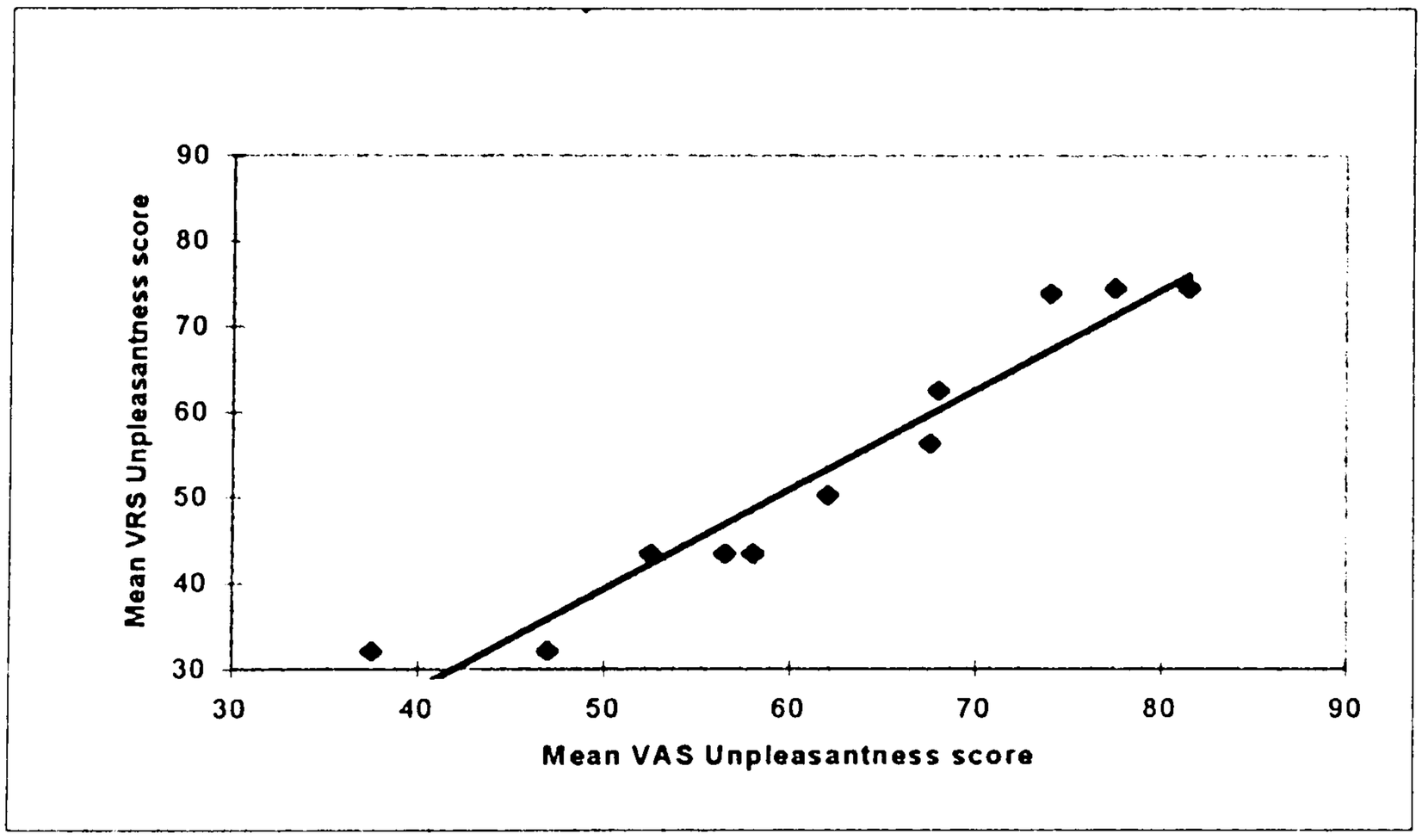


Figure IV : Correlation of mean VAS and VRS pain unpleasantness scores



Tables 1a and 1b in text (Chapter 8)

Table 1c : Raw VAS pain intensity scores for experiment 1

Subject	1	2	3	4	5	6	7	8	9	10	11	12
Min 1	58	69	36	45	72	54	19	49	19	38	43	36
Min 2	48	77	39	56	85	50	38	48	25	47	34	54
Min 3	42	87	39	60		66	40	48	29		33	48
Min 4	56	93	38	66		67	39	50	30		33	55
Min 5	62	88	40	59		65	44	46	33		37	58
Min 6	63	97	50	75		67	63	52	38		40	56
Min 7	73		48	75		78	71	66	44		39	57
Min 8	80		55	82		74	84	78	48		48	55
Min 9			58			92	89	76	61			65
Min 10			61			94	90	94	58			71
Min 11							92		70			

Table 1d : Raw VRS pain intensity scores for experiment 1

Subject	1	2	3	4	5	6	7	8	9	10	11	12
Min 1	64.5	72.6	38.2	20.5	95.8	44.8	13.6	38.2	20.5	38.2	44.8	38.2
Min 2	44.8	84.8	38.2	38.2	95.8	44.8	38.2	38.2	20.5	38.2	38.2	38.2
Min 3	38.2	95.8	38.2	38.2		64.5	38.2	38.2	38.2		38.2	38.2
Min 4	64.5	95.8	38.2	44.8		64.5	38.2	44.8	38.2		38.2	44.8
Min 5	64.5	95.8	38.2	38.2		64.5	44.8	38.2	38.2		44.8	44.8
Min 6	64.5	100	44.8	64.5		72.6	64.5	44.8	38.2		38.2	64.5
Min 7	72.6		44.8	64.5		84.8	84.8	64.5	38.2		38.2	44.8
Min 8	84.8		44.8	72.6		84.8	95.8	72.6	44.8		44.8	64.5
Min 9			64.5			84.8	95.8	84.8	64.5			72.6
Min 10			64.5			95.8	95.8	95.8	64.5			72.6
Min 11							95.8		64.5			

Table 1e : Summary of descriptive statistics (VAS and VRS intensity scores) for experiment 1

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
VAS						
Min 1	44.83±16.89	44.00	285.24	0.68	0.02	-0.49
Min 2	50.08±16.97	48.00	288.08	0.35	0.87	0.74
Min 3	49.20±17.45	45.00	304.62	0.31	1.18	1.28
Min 4	52.70±19.25	52.50	370.68	0.44	0.89	0.76
Min 5	53.20±16.55	52.00	273.96	0.44	0.88	0.81
Min 6	60.10±17.40	59.50	302.77	0.53	0.88	1.19
Min 7	61.22±14.63	66.00	213.94	0.35	-0.43	-1.60
Min 8	67.11±15.26	74.00	232.86	0.06	-0.25	-2.18
Min 9	73.50±14.54	70.50	211.50	0.28	0.37	-2.15
Min 10	78.00±16.70	80.50	278.80	0.08	-0.21	-2.67
Min 11	81.00±15.56	81.00	242.00	N/A	N/A	N/A
VRS						
Min 1	44.16±23.52	38.20	553.24	0.26	0.95	0.83
Min 2	46.51±21.45	38.20	460.13	<0.01	1.70	2.33
Min 3	46.59±19.16	38.20	367.28	<0.01	2.37	5.38
Min 4	51.20±18.68	44.80	349.09	<0.01	1.78	3.07
Min 5	51.20±18.68	44.80	349.09	<0.01	1.78	3.07
Min 6	59.67±19.01	64.50	361.24	0.15	0.85	1.01
Min 7	59.69±18.84	64.50	355.13	0.22	0.18	-1.71
Min 8	67.72±19.38	72.60	375.74	0.28	-0.08	-1.50
Min 9	77.83±12.67	78.70	160.56	0.35	0.23	-1.56
Min 10	81.50±15.94	84.20	254.14	0.02	-0.13	-3.01
Min 11	80.15±22.13	80.15	489.84	N/A	N/A	N/A

Table 1f : Raw VAS pain unpleasantness scores for experiment 1

Subject	1	2	3	4	5	6	7	8	9	10	11	12
Min 1	52	61	31	61	63	71	15	39	19	58	41	53
Min 2	39	77	36	58	88	62	28	49	25	67	28	36
Min 3	51	90	37	34		51	32	50	29		31	43
Min 4	56	88	41	61		44	42	56	30		30	57
Min 5	60	91	45	47		59	52	53	33		44	56
Min 6	63	98	45	76		70	67	60	38		40	61
Min 7	66		54	79		81	73	63	44		44	69
Min 8	92		60	79		80	88	76	48		55	63
Min 9			62			87	90	82	61			68
Min 10			77			91	93	96	58			74
Min 11							93		70			

Table 1g : Raw VRS pain unpleasantness scores for experiment 1

Subject	1	2	3	4	5	6	7	8	9	10	11	12
Min 1	50.2	50.2	27.6	27.6	62.4	62.4	18.7	36.6	27.6	62.4	27.6	36.6
Min 2	36.6	62.4	27.6	27.6	73.9	62.4	27.6	36.6	27.6	62.4	27.6	27.6
Min 3	36.6	73.9	27.6	27.6		50.2	27.6	36.6	27.6		27.6	27.6
Min 4	50.2	73.9	27.6	27.6		50.2	36.6	50.2	27.6		27.6	36.6
Min 5	50.2	86.5	27.6	27.6		62.4	50.2	50.2	27.6		36.6	36.6
Min 6	50.2	100	36.6	50.2		62.4	62.4	62.4	27.6		36.6	50.2
Min 7	62.4		50.2	50.2		73.9	62.4	62.4	27.6		50.2	50.2
Min 8	86.5		62.4	50.2		73.9	73.9	62.4	36.6		62.4	62.4
Min 9			62.4			73.9	73.9	73.9	50.2			62.4
Min 10			73.9			86.5	86.5	86.5	50.2			73.9
Min 11							86.5		62.4			

Table 1h: Summary of descriptive statistics (VAS and VRS unpleasantness scores) for experiment 1

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
VAS						
Min 1	47.00±18.01	52.50	324.54	0.39	-0.64	-0.70
Min 2	49.42±20.83	44.00	433.90	0.39	0.56	-0.87
Min 3	44.80±18.05	40.00	325.73	<0.01	1.95	4.55
Min 4	50.50±17.21	50.00	296.06	0.30	0.97	1.54
Min 5	54.00±15.31	52.50	234.44	0.08	1.53	3.96
Min 6	61.80±18.06	62.00	326.18	0.54	0.53	0.56
Min 7	63.67±13.80	66.00	190.50	0.44	-0.39	-1.16
Min 8	71.22±15.29	76.00	233.69	0.66	-0.17	-1.35
Min 9	75.00±12.90	75.00	166.40	0.19	0.02	-2.63
Min 10	81.50±14.57	84.00	212.30	0.39	-0.78	-0.37
Min 11	81.50±16.26	81.50	264.50	N/A	N/A	N/A
VRS						
Min 1	40.82±15.95	36.60	254.28	0.08	0.31	-1.53
Min 2	41.66±18.01	32.10	324.29	<0.01	0.81	-1.23
Min 3	36.29±15.13	27.60	229.03	<0.01	2.08	4.28
Min 4	40.81±15.25	36.60	232.55	0.04	1.15	1.09
Min 5	45.55±18.72	43.40	350.28	0.10	1.16	1.38
Min 6	53.86±20.20	50.20	408.14	0.18	1.20	2.48
Min 7	54.39±13.04	50.20	170.13	0.24	-0.76	1.66
Min 8	63.41±14.36	62.40	206.32	0.51	-0.38	0.81
Min 9	66.12±9.62	68.15	92.54	0.08	-0.92	-0.07
Min 10	76.25±14.18	80.20	200.97	0.04	-1.52	2.31
Min 11	74.45±17.04	74.45	290.40	N/A	N/A	N/A

Appendix 2 :Experiment 2 - Tables

Figures V and V1 in text (Chapter 9)
Tables 2a and 2b in text (Chapter 9)

Table 2c - Raw VAS intensity data for experiment 2 (including summary of descriptive statistics)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
200mmHg													
Min 1	61	24	18	30	28	34	34	32.71±13.70	30.00	187.57	0.10	1.69	3.8
Min 2	72	22	14	31	41	37	32	35.57±18.45	32.00	340.29	0.36	1.33	2.71
Min 3	69	33	17	37	35	42	26	37.00±16.28	35.00	265.00	0.38	1.27	2.73
Min 4	74	33	21	42	49	47	38	43.43±16.44	42.00	273.90	0.69	0.85	1.78
Min 5	72	36	21	53	62	50	39	47.57±17.10	50.00	292.29	0.99	-0.15	-0.36
Min 6	78	34	23	52	69	49	45	50.00±18.97	49.00	360.00	0.90	0.17	-0.56
Min 7	89	31	23	65	67	50	45	52.86±22.70	50.00	515.48	0.90	0.28	-0.49
Min 8	88	33	23	63	69	47	41	52.00±22.56	47.00	509.00	0.90	0.41	-0.66
Min 9	83	39	26	67	72	52	46	55.00±20.02	52.00	400.67	0.93	-0.19	-1.04
Min 10	86	40	29	72	74	64	44	58.43±20.94	64.00	438.62	0.60	-0.19	-1.57
Min 11	84	40	38	78	76	61	45	60.29±19.43	61.00	324.24	0.45	-0.05	-1.97
Min 12	90	54	39	82	73	60	41	62.71±19.75	60.00	389.90	0.57	0.13	-1.57
Min 13	90	52	49	86	72	68	43	65.71±18.39	68.00	338.24	0.47	0.15	-1.73
Min 14	88	59	43	88	76	55	41	64.29±19.88	59.00	395.24	0.30	0.15	-1.94
Min 15	87	58	47	97	75	62	47	67.57±19.44	62.00	377.95	0.45	0.47	-1.27
250mmHg													
Min 1	56	25	9	8	57	54	26	33.57±21.82	26.00	476.29	0.09	0.001	-2.25
Min 2	56	25	13	8	65	53	39	37.00±22.23	39.00	505.57	0.44	-0.16	-1.90
Min 3	65	29	24	14	54	53	44	40.43±18.52	44.00	342.95	0.70	-0.18	-1.43
Min 4	63	33	25	23	57	63	57	45.86±18.07	57.00	326.48	0.05	-0.41	-2.36
Min 5	61	34	26	26	63	62	59	47.29±17.66	59.00	311.90	0.02	-0.44	-2.50
Min 6	68	33	40	33	64	62	56	50.86±15.13	56.00	228.81	0.16	-0.26	-2.28
Min 7	69	36	50	34	60	64	59	53.14±13.67	59.00	186.81	0.35	-0.57	-1.37
Min 8	69	38	56	39	68	66	61	56.71±13.21	61.00	174.57	0.08	-0.80	-1.30
Min 9	75	55	61	43	55	66	58	59.00±9.98	58.00	99.67	0.92	0.05	0.89
Min 10	77	43	58	39	65	60	55	56.71±12.89	58.00	166.24	0.84	0.08	-0.20
Min 11	83	46	73	42	65	62	54	60.71±14.60	62.00	213.24	0.89	0.22	-0.87
Min 12	83	62	76	54	63	66	44	64.00±13.00	63.00	169.00	0.96	-0.04	-0.15
Min 13	84	59	85	63	73	67	40	67.29±15.59	67.00	242.90	0.61	-0.65	0.43
Min 14	85	69	78	61	69	69	49	68.57±11.54	69.00	133.29	0.72	-0.40	0.66
Min 15	84	79	72	64	77	75	42	70.43±13.99	75.00	195.62	0.12	-1.68	3.09

Table 2d - Raw VAS unpleasantness data for experiment 2 (including summary of descriptive statistics)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
200mmHg													
Min 1	77	16	12	28	25	28	28	30.57±21.46	28.00	460.62	<0.01	2.13	5.18
Min 2	86	24	15	30	45	45	26	38.71±23.56	30.00	555.24	0.17	1.55	2.77
Min 3	87	31	14	30	38	45	23	38.29±23.68	31.00	560.57	0.14	1.71	3.57
Min 4	91	35	13	33	50	55	36	44.71±24.46	36.00	598.24	0.46	1.04	1.96
Min 5	91	37	16	47	49	59	37	48.00±23.23	47.00	539.67	0.61	0.84	1.83
Min 6	93	45	18	54	61	70	43	54.86±23.52	54.00	553.14	0.98	0.12	0.77
Min 7	95	47	13	61	65	77	43	57.29±26.32	61.00	692.57	0.98	-0.37	0.51
Min 8	95	45	20	62	75	70	42	58.43±24.78	62.00	614.29	0.98	-0.13	-0.24
Min 9	94	46	24	72	66	72	38	58.86±23.97	66.00	574.48	0.80	-0.09	-0.76
Min 10	92	52	34	75	70	79	40	63.14±21.53	70.00	463.48	0.61	-0.20	-1.49
Min 11	95	61	32	82	76	78	35	65.57±24.09	76.00	580.29	0.35	-0.56	-1.24
Min 12	96	67	44	82	80	80	43	70.29±20.14	80.00	405.57	0.29	-0.52	-1.13
Min 13	97	56	51	86	76	81	36	69.00±21.79	76.00	474.67	0.73	-0.34	-1.17
Min 14	96	67	53	86	75	79	46	71.71±17.75	75.00	315.24	0.87	-0.25	-0.93
Min 15	97	72	53	98	73	83	46	74.57±20.06	73.00	402.29	0.48	-0.25	-1.24
250mmHg													
Min 1	48	16	7	7	30	50	56	30.57±21.02	30.00	452.24	0.18	0.02	-2.33
Min 2	46	24	12	10	32	54	58	33.71±19.51	32.00	383.95	0.42	0.02	-1.94
Min 3	54	31	14	16	40	56	59	38.57±18.85	40.00	360.90	0.27	-0.27	-2.01
Min 4	54	35	26	26	50	70	61	46.00±17.33	50.00	296.81	0.46	0.0005	-1.60
Min 5	54	37	28	33	47	75	59	47.57±16.49	47.00	268.57	0.82	0.54	-0.36
Min 6	58	45	49	32	47	78	57	52.29±14.26	49.00	222.95	0.80	0.69	0.87
Min 7	58	47	45	33	56	74	59	53.14±12.98	56.00	173.14	0.82	0.11	0.28
Min 8	68	45	60	34	64	75	62	58.29±14.08	62.00	179.67	0.49	-1.10	1.39
Min 9	72	46	69	36	58	71	43	56.43±14.84	58.00	220.29	0.28	-0.23	-2.06
Min 10	82	52	70	35	64	84	54	63.00±17.50	64.00	293.95	0.71	-0.44	-0.16
Min 11	88	61	71	43	65	88	37	64.71±19.91	65.00	395.14	0.44	-0.21	-1.20
Min 12	89	67	85	40	77	90	38	69.43±22.23	77.00	495.62	0.05	-0.95	-1.08
Min 13	89	56	88	41	66	93	36	67.00±23.66	82.00	561.24	0.10	-0.78	-1.40
Min 14	83	67	93	49	60	91	42	69.29±20.29	83.00	458.57	0.15	-0.52	-1.98
Min 15	88	72	85	58	67	94	40	72.00±18.95	85.00	428.14	0.27	-0.86	-0.55

Table 2e : Summary of experiment 2 questionnaire responses

	cuff pressure (mmHg)	time test lasted (mins)	why test stopped	diff. in int. and unp.	VAS marked approp.?	difference between cuff and arm?	more pain - cuff or arm?	extra info
subject 1 (1st test)	200	15		yes	no	no		
subject 1 (2nd test)	250	15		yes	yes	yes	arm	less pain than 1st
subject 2 (1st test)	200	15		yes	yes	yes	arm	
subject 2 (2nd test)	250	15		yes	yes	yes	arm	more pain unp, esp hand
subject 3 (1st test)	250	15		yes	yes	yes	cuff	worst pain unp - cuff deflation
subject 3 (2nd test)	200	15		yes	no	no		less pain than 1st
subject 4 (1st test)	200	15		yes	yes	yes	cuff	
subject 4 (2nd test)	250	15		yes	yes	yes	cuff	
subject 5 (1st test)	200	15		yes	no	no		VAS scales too high
subject 5 (2nd test)	250	15		yes	yes	yes	cuff	same pain as 1st
subject 6 (1st test)	250	12	pain and nausea	yes	yes	yes	arm	discomfort, not pain
subject 6 (2nd test)	200	9	dizzy, flushed and nausea	yes	yes	yes	arm	time of day increased pain - early morning
subject 7 (1st test)	250	15		yes	yes	yes	cuff	strange, not pain - VAS too high
subject 7 (2nd test)	200	15		yes	yes	yes	cuff	less anxiety than 1st
subject 8 (1st test)	250	15		yes	yes	yes	arm and hand	less pain than expected
subject 8 (2nd test)	200	15		yes	yes	yes	arm	
Total and / or mean (200mmHg)		14.25		yes = 8	yes = 7 no = 1	yes = 5 no = 3	cuff = 2 arm = 3	
Total and / or mean (250mmHg)		14.625		yes = 8	yes = 8	yes = 8	cuff = 4 arm = 4	

Appendix 3 : Experiment 3 - Graphs and Tables

Figures VII and VIII in text (Chapter 10)
Tables 3a, 3b and 3c in text (Chapter 10)

Figure IX (i) Individual pain VAS intensity scores in 1st test

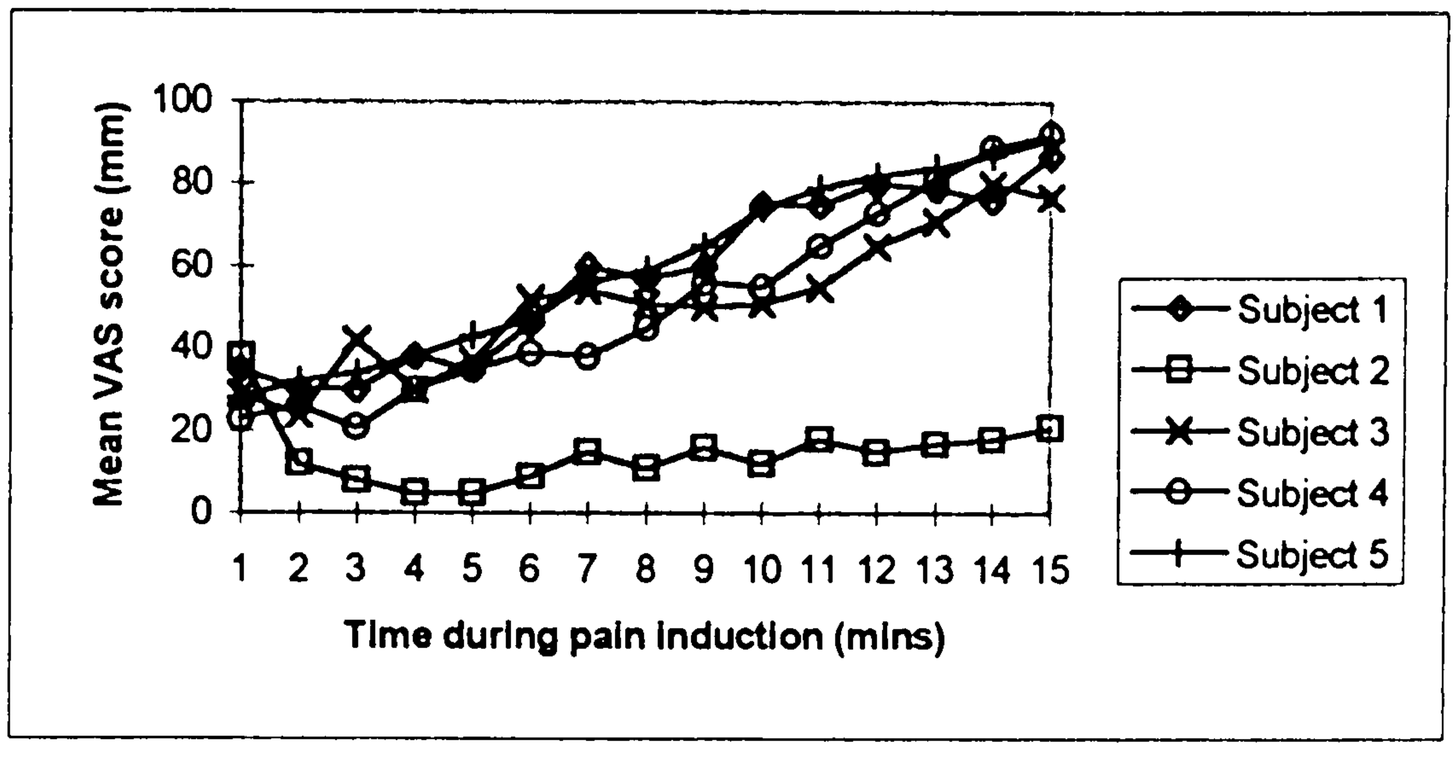


Figure IX (ii) Individual pain VAS intensity scores in 2nd test

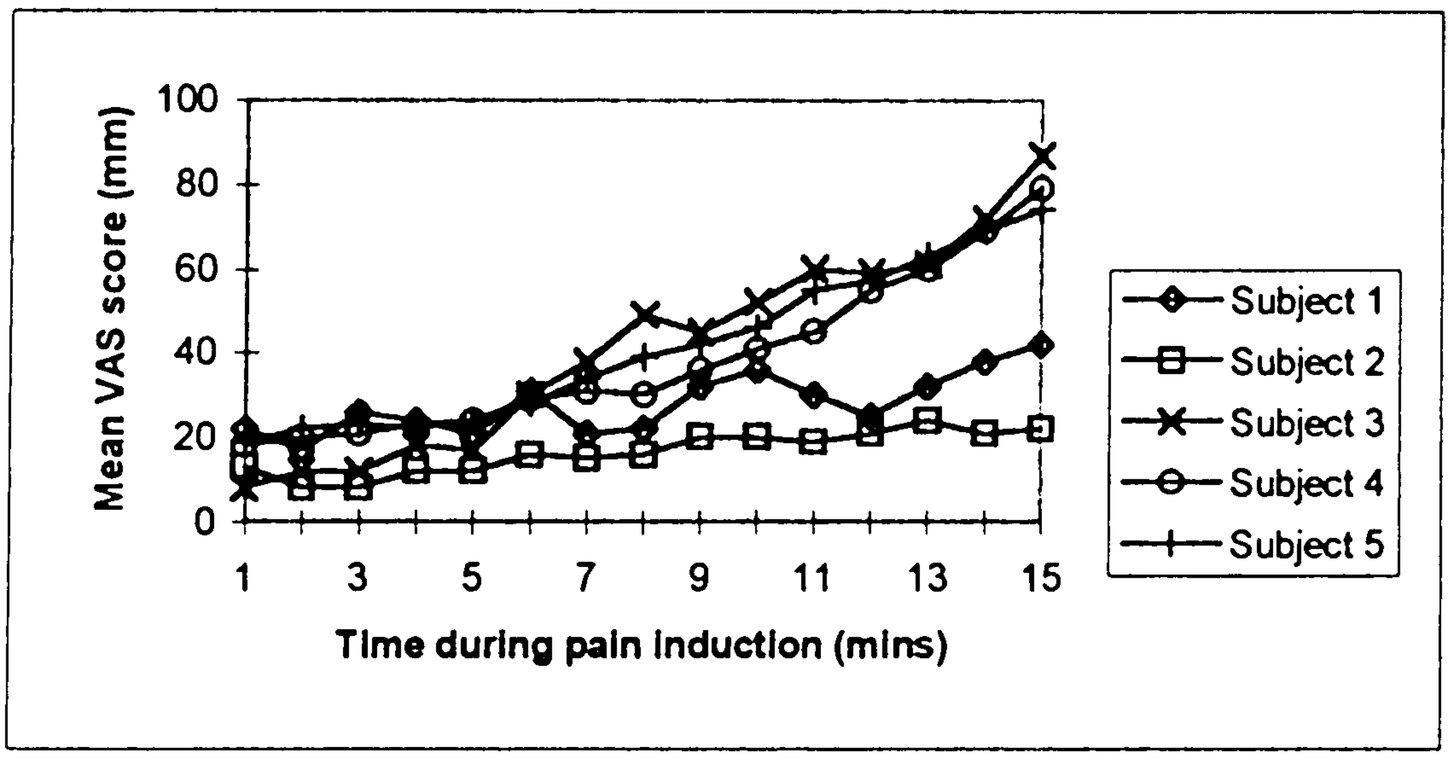


Figure IX (iii) Individual pain VAS intensity scores in 3rd test

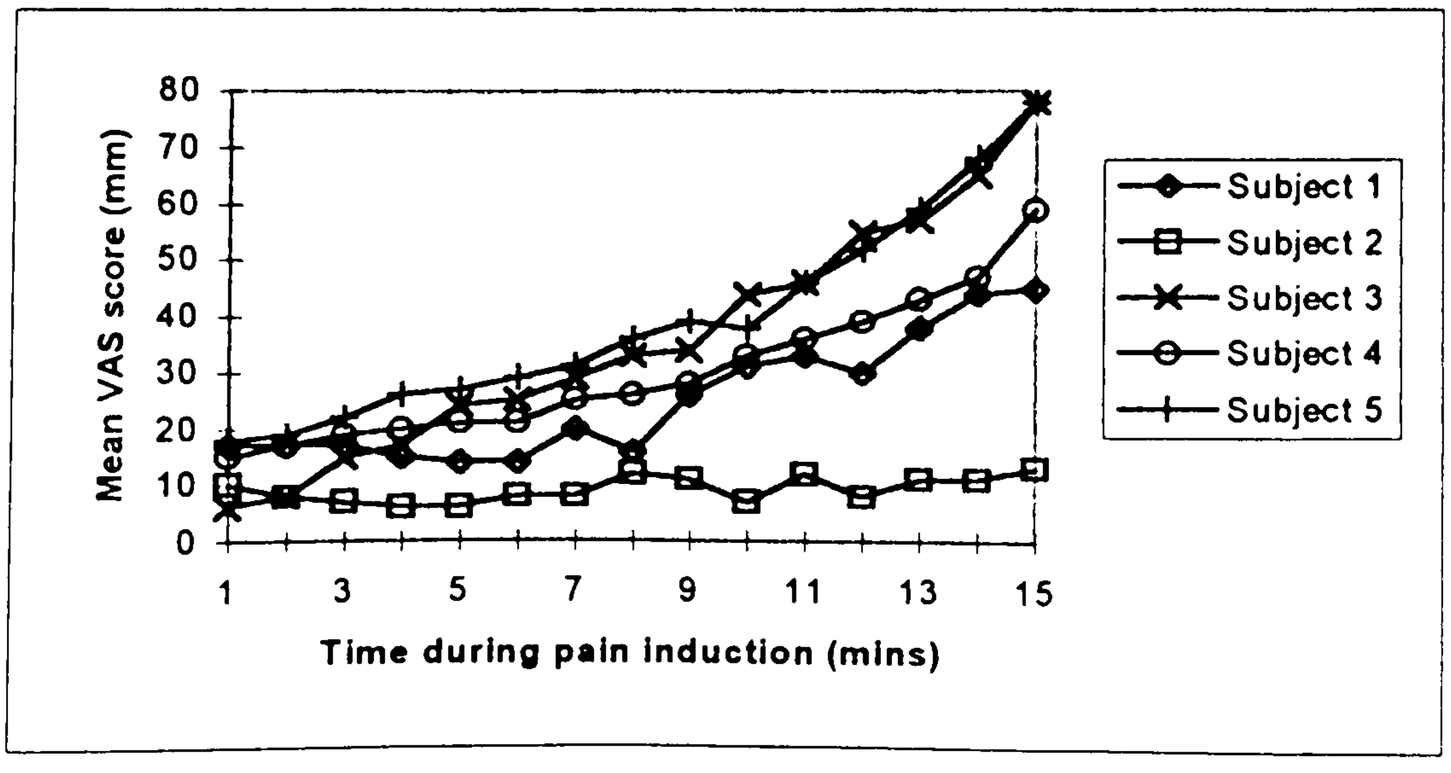


Figure X(i) : Individual VAS pain unpleasantness scores in 1st test

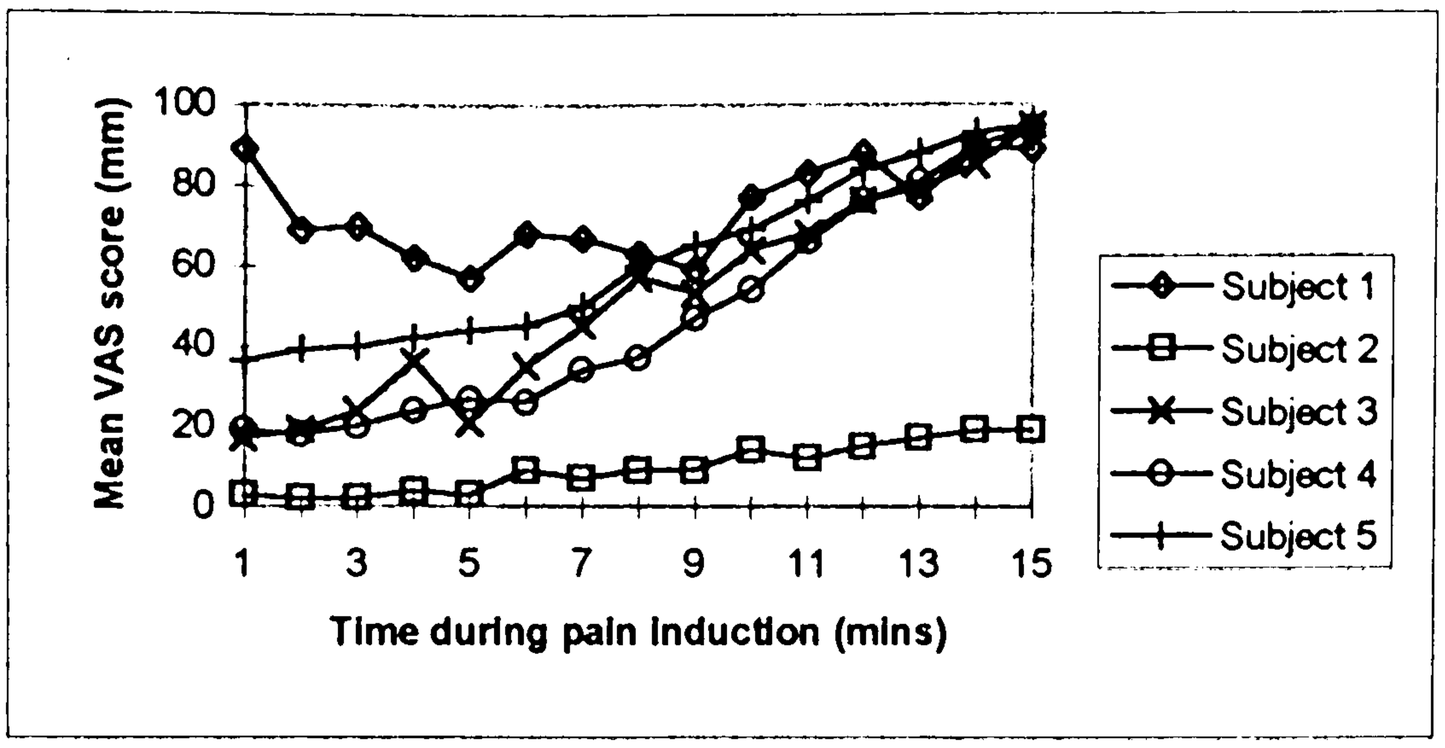


Figure X(ii) : Individual VAS pain unpleasantness scores in 2nd test

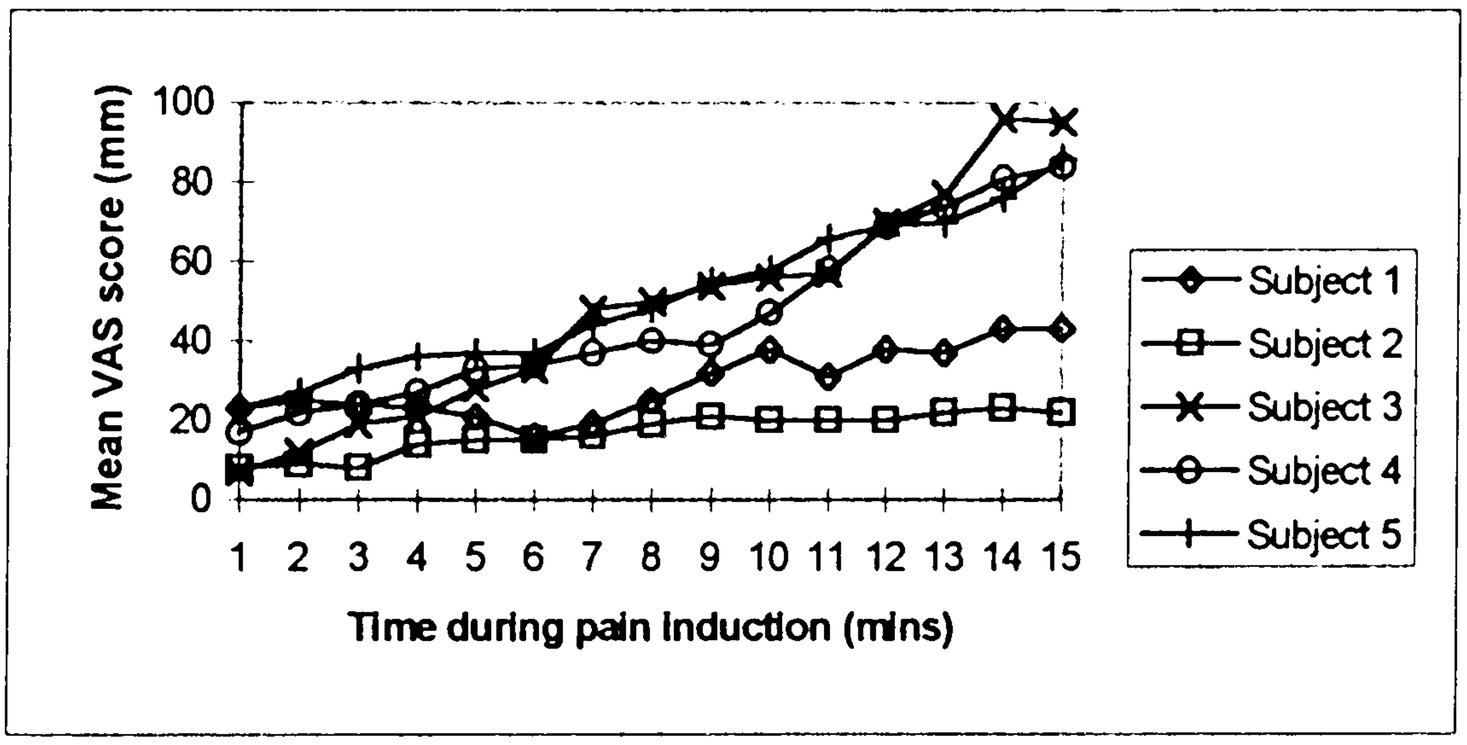


Figure X(iii) : Individual VAS pain unpleasantness scores in 3rd test

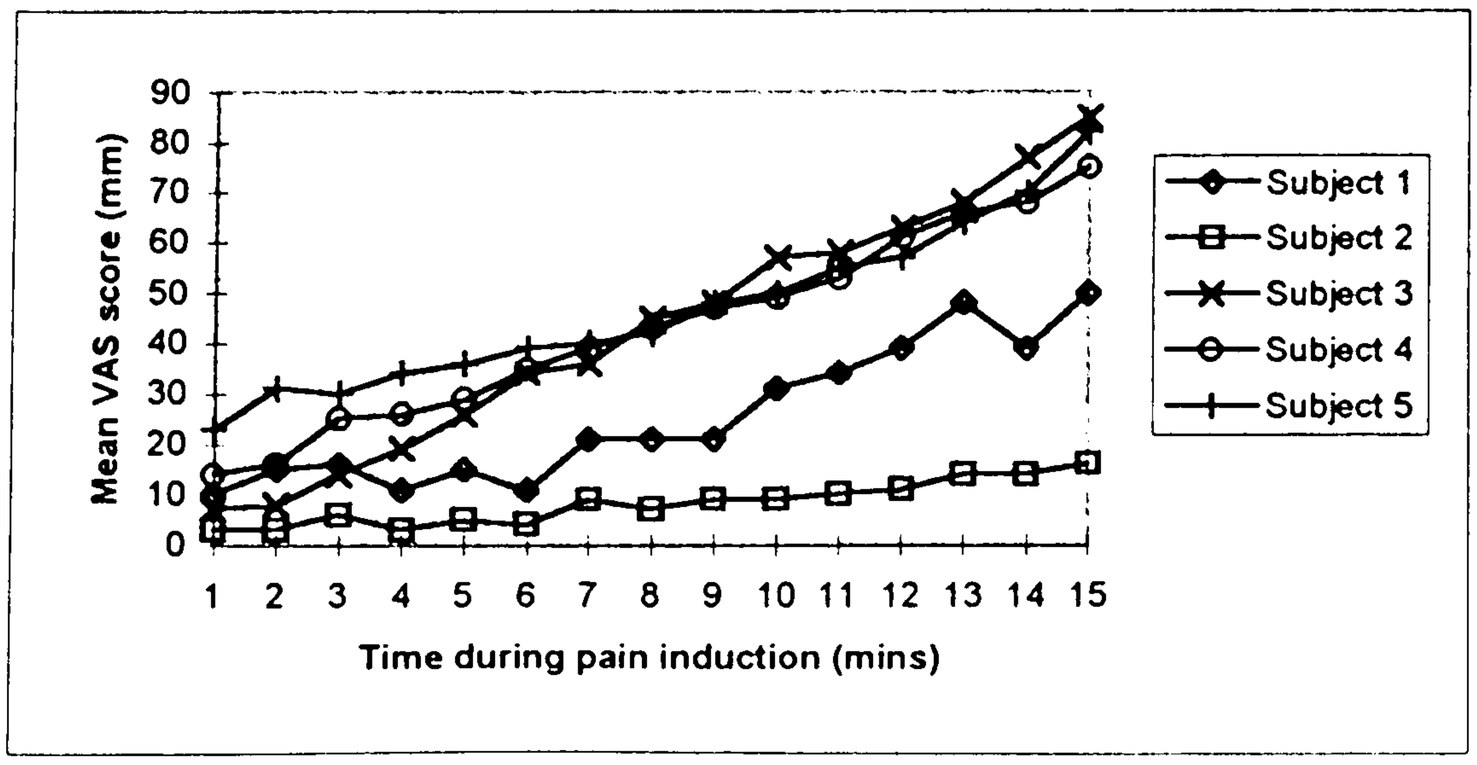


Table 3d : Simple main effects for VAS pain intensity scores in experiment 3

A = test (1st, 2nd and 3rd test)

b = time b1 = min 1
b2 = min 2.....

Critical value = 3.07-4.46
* = significant result $p \leq 0.05$

	Mean Square (MS)	F value
A at b1 :	436.47	5.79*
A at b2 :	171.67	2.28
A at b3 :	171.67	2.28
A at b4 :	174.60	2.31
A at b5 :	241.80	3.21*
A at b6 :	468.87	6.22*
A at b7 :	661.07	8.77*
A at b8 :	519.27	6.89*
A at b9 :	614.47	8.15*
A at b10 :	664.80	8.82*
A at b11 :	744.87	9.88*
A at b12:	928.47	12.31*
A at b13 :	828.80	10.99*
A at b14 :	698.07	9.26*
A at b15 :	469.40	6.22*

Table 3e : Raw VAS intensity data for experiment 3 (including summary of descriptive statistics)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Mean ± S.D.	Median	Variance	Shapiro - Wilk (p)	Skew ness	Kurt osis
1ST TEST											
Min 1	35	38	29	23	28	30.60±5.94	29.00	35.30	0.57	0.06	-1.22
Min 2	30	12	24	26	32	24.80±7.82	26.00	61.20	0.37	-1.38	2.10
Min 3	30	8	42	21	34	27.00±13.04	30.00	170.00	0.76	-0.63	-0.01
Min 4	38	5	30	30	38	28.20±13.57	30.00	184.20	0.07	-1.76	3.35
Min 5	35	5	37	35	43	31.00±14.90	35.00	222.00	0.08	-1.95	4.16
Min 6	46	9	52	39	47	38.60±17.18	46.00	295.30	0.10	-1.85	3.58
Min 7	60	15	54	38	56	44.60±18.54	54.00	343.80	0.21	-1.32	0.99
Min 8	57	11	51	45	59	44.60±19.57	51.00	382.80	0.09	-1.82	3.45
Min 9	60	16	50	56	65	49.40±19.46	56.00	378.80	0.16	-1.81	3.48
Min 10	75	12	51	55	74	53.40±25.56	55.00	653.30	0.25	-1.30	1.77
Min 11	75	18	55	65	79	58.40±24.43	65.00	596.80	0.27	-1.50	2.25
Min 12	80	15	65	73	82	63.00±27.65	73.00	764.50	0.06	-1.93	3.83
Min 13	79	17	71	81	84	66.40±28.03	79.00	785.80	0.03	-2.08	4.39
Min 14	76	18	80	89	87	70.00±29.54	80.00	872.50	0.03	-2.06	4.37
Min 15	87	21	77	92	91	73.60±30.00	87.00	899.80	0.03	-2.03	4.19
2ND TEST											
Min 1	22	13	8	18	19	16.00±5.52	18.00	30.50	0.50	-0.71	-0.51
Min 2	17	8	12	20	22	15.80±5.76	17.00	33.20	0.44	-0.47	-1.53
Min 3	26	8	12	21	23	18.00±7.65	21.00	58.50	0.30	-0.51	-2.12
Min 4	24	12	18	23	22	19.80±4.92	22.00	24.20	0.26	-1.27	0.86
Min 5	21	12	17	24	24	19.60±5.13	21.00	26.30	0.23	-0.88	-0.53
Min 6	31	16	30	29	28	26.80±6.14	29.00	37.70	0.04	-2.05	4.35
Min 7	21	15	38	31	34	27.80±9.52	31.00	90.70	0.39	-0.52	-1.71
Min 8	22	16	49	30	39	31.20±13.18	30.00	173.70	0.61	0.33	-1.18
Min 9	32	20	45	36	42	35.00±9.80	36.00	96.00	0.50	-0.91	0.56
Min 10	36	20	52	41	46	39.00±12.17	41.00	148.00	0.65	-1.00	1.21
Min 11	30	19	60	45	55	41.80±17.14	45.00	293.70	0.40	-0.42	-1.77
Min 12	25	21	59	55	57	43.40±18.73	55.00	350.80	0.02	-0.61	-3.14
Min 13	32	24	61	60	63	48.00±18.51	60.00	342.50	0.03	-0.70	-2.70
Min 14	38	21	72	69	69	53.80±23.02	69.00	529.70	0.06	-0.89	-1.60
Min 15	42	22	87	79	74	60.80±27.62	74.00	762.70	0.25	-0.77	-1.55
3RD TEST											
Min 1	17	10	6	15	18	13.20±5.07	15.00	25.70	0.30	-0.75	-1.30
Min 2	17	8	8	17	19	13.80±5.36	17.00	28.70	0.02	-0.50	-3.14
Min 3	17	7	15	19	22	16.00±5.66	17.00	32.00	0.61	-1.12	1.69
Min 4	15	6	17	20	26	16.80±7.33	17.00	53.70	0.97	-0.48	1.05
Min 5	14	6	24	21	27	18.40±8.44	21.00	71.30	0.45	-0.80	-0.50
Min 6	14	8	25	21	29	19.40±8.44	21.00	71.30	0.54	-0.40	-1.31
Min 7	20	8	29	25	31	22.60±9.18	25.00	84.30	0.38	-1.22	1.18
Min 8	16	12	33	26	36	24.60±10.43	26.00	108.80	0.29	-0.20	-2.45
Min 9	26	11	34	28	39	27.60±10.60	28.00	112.30	0.62	-0.99	1.37
Min 10	31	7	44	33	38	30.60±14.12	33.00	199.30	0.36	-1.53	2.87
Min 11	33	12	46	36	46	34.60±13.92	36.00	193.80	0.22	-1.32	1.81
Min 12	30	8	55	39	52	36.80±18.99	39.00	360.70	0.41	-0.89	0.20
Min 13	38	11	57	43	59	41.60±19.31	43.00	372.80	0.34	-1.14	1.22
Min 14	44	11	65	47	68	47.00±22.75	47.00	517.50	0.35	-1.12	1.24
Min 15	45	13	78	59	78	54.60±27.10	59.00	734.30	0.28	-0.99	0.35

Table 3f : Raw VAS unpleasantness data for experiment 3 (including summary of descriptive statistics)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Mean± S.D.	Median	Variance	Shapiro - Wilk (p)	Skew ness	Kurt osis
1ST TEST											
Min 1	89	3	17	19	36	32.80±33.53	19.00	1124.20	0.28	1.60	2.74
Min 2	69	2	19	18	39	29.40±25.74	19.00	662.30	0.50	0.97	0.72
Min 3	70	2	24	20	40	31.20±25.56	24.00	653.20	0.75	0.81	0.84
Min 4	62	4	36	24	42	33.60±21.51	36.00	462.80	0.99	-0.14	0.36
Min 5	57	3	21	27	44	30.40±20.88	27.00	435.80	0.79	-0.01	-0.72
Min 6	68	9	35	26	45	36.60±21.98	35.00	483.30	0.97	0.37	0.40
Min 7	67	7	45	34	50	40.60±22.23	45.00	494.30	0.87	-0.72	1.06
Min 8	63	9	57	37	60	45.20±22.65	57.00	513.20	0.14	-1.34	0.97
Min 9	59	9	53	47	65	46.60±22.06	53.00	486.80	0.21	-1.74	3.28
Min 10	77	14	64	54	69	55.60±24.70	64.00	610.30	0.27	-1.64	2.88
Min 11	83	12	68	66	76	61.00±28.21	68.00	796.00	0.09	-1.91	3.94
Min 12	88	15	76	76	84	67.80±29.97	76.00	898.20	0.03	-2.07	4.42
Min 13	77	17	79	81	88	68.40±29.03	79.00	842.80	0.02	-2.12	4.62
Min 14	89	19	85	90	93	75.20±31.55	89.00	995.20	<0.01	-2.19	4.83
Min 15	89	19	95	94	95	78.40±33.30	94.00	1108.80	<0.01	-2.21	4.88
2ND TEST											
Min 1	23	8	7	17	23	15.60±7.80	17.00	60.80	0.05	-0.23	-2.99
Min 2	25	9	12	22	27	19.00±8.03	22.00	64.50	0.16	-0.47	-2.63
Min 3	24	8	19	24	33	21.60±9.13	24.00	83.30	0.85	-0.56	1.22
Min 4	23	14	21	27	36	24.20±8.11	23.00	65.70	0.97	0.44	0.80
Min 5	21	15	28	33	37	26.80±8.90	28.00	79.20	0.52	-0.32	-1.46
Min 6	16	15	33	34	37	27.00±10.61	33.00	112.50	0.03	-0.52	-3.15
Min 7	19	16	48	37	44	32.80±14.55	37.00	211.70	0.13	-0.32	-2.83
Min 8	25	19	50	40	48	36.40±13.83	40.00	191.30	0.19	-0.41	-2.50
Min 9	32	21	54	39	55	40.20±14.55	39.00	211.70	0.31	-0.24	-1.73
Min 10	38	20	56	47	58	43.80±15.50	47.00	240.20	0.36	-1.00	0.34
Min 11	31	20	57	58	66	46.40±19.78	57.00	391.30	0.20	-0.63	-2.12
Min 12	38	20	70	69	69	53.20±22.99	69.00	528.70	0.04	-0.94	-1.41
Min 13	37	22	77	74	70	56.00±24.89	70.00	619.50	0.08	-0.76	-2.12
Min 14	43	23	96	81	76	63.80±29.91	76.00	894.70	0.40	-0.57	-1.53
Min 15	43	22	95	84	86	66.00±31.74	84.00	1007.50	0.15	-0.77	-1.84
3RD TEST											
Min 1	10	3	7	14	23	11.40±7.64	10.00	58.30	0.72	0.84	0.65
Min 2	15	3	8	16	31	14.60±10.60	15.00	112.30	0.62	0.90	1.15
Min 3	16	6	14	25	30	18.20±9.44	16.00	89.20	0.64	0.03	-1.08
Min 4	11	3	19	26	34	18.60±12.18	19.00	148.30	0.75	-0.04	-1.08
Min 5	15	5	26	29	36	22.20±9.44	26.00	149.70	0.57	-0.56	-0.81
Min 6	11	4	34	35	39	24.60±15.92	34.00	253.30	0.07	-0.65	-2.61
Min 7	21	9	36	39	40	29.00±13.55	36.00	183.50	0.11	-0.98	-0.90
Min 8	21	7	45	43	42	31.60±16.85	42.00	283.30	0.08	-0.96	-1.18
Min 9	21	9	48	47	48	34.60±18.39	47.00	338.30	0.03	-0.84	-1.97
Min 10	31	9	57	49	50	39.20±19.42	49.00	377.20	0.31	-1.15	0.43
Min 11	34	10	58	53	55	42.00±20.21	53.00	408.50	0.14	-1.29	0.70
Min 12	39	11	63	61	57	46.20±21.84	57.00	477.20	0.13	-1.39	1.22
Min 13	48	14	68	66	64	52.0022.67	64.00	514.00	0.07	-1.66	2.46
Min 14	39	14	77	68	70	53.60±24.68	68.00	701.30	0.21	-1.01	-0.58
Min 15	50	16	85	75	82	61.60±28.97	75.00	839.30	0.19	-1.24	0.60

Appendix 4 : Experiment 4 - Tables

Figures XI, XII and XIII in text (Chapter 11)
Tables 4a and 4b in text (Chapter 11)

Table 4c : ANOVA Table for TENS current intensity scores before pain induction in experiment 4 (100Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	25.07	1	25.07	0.21	0.655
Error (Within + Residual)	1304.23	11	118.57		
Effect of Time					
Time	272.07	14	19.43	25.71	<0.001
Error (Within + Residual)	116.40	154	0.76		
Interaction (Condition x Time)					
Condition x Time	13.39	14	0.96	1.43	0.144
Error (Within + Residual)	102.81	154	0.67		

Table 4d : ANOVA Table for TENS current intensity scores during pain induction in experiment 4 (100Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	183.47	1	183.47	1.73	0.216
Error (Within + Residual)	1169.16	11	106.29		
Effect of Time					
Time	85.23	14	6.09	7.18	<0.001
Error (Within + Residual)	130.50	154	0.85		
Interaction (Condition x Time)					
Condition x Time	28.32	14	2.02	2.79	0.001
Error (Within + Residual)	111.54	154	0.72		

Table 4e : Raw VAS intensity data for experiment 4 (100Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
NO TENS												
Min 1	38	6	10	7	29	55	39	3	6	2	49	27
Min 2	41	8	14	10	34	60	40	7	8	2	55	32
Min 3	43	10	18	13	30	67	55	12	7	2	59	36
Min 4	42	12	15	14	34	59	60	12	10	4	53	36
Min 5	42	12	14	19	39	57	61	15	18	6	63	33
Min 6	43	14	15	22	39	65	58	26	24	4	61	39
Min 7	43	12	13	24	53	62	62	33	21	5	64	36
Min 8	37	18	18	27	52	64	63	19	25	9	69	38
Min 9	39	15	14	24	50	68	62	28	38	5	66	45
Min 10	43	22	17	33	58	67	65	41	42	5	71	42
Min 11	40	20	19	43	55	69	68	45	44	9	68	42
Min 12	40	22	18	47	56	78	68	49	40	7	68	42
Min 13	46	23	17	47	61	80	73	44	49	7	77	41
Min 14	36	22	37	44	67	85	72	44	43	5	80	47
Min 15	42	28	21	55	71	88	74	59	51	11	81	47
EXPT. CONTROL												
Min 1	36	13	5	9	20	69	57	8	5	4	39	22
Min 2	32	16	5	9	32	65	62	13	12	1	42	24
Min 3	24	20	10	5	24	63	67	17	13	1	43	31
Min 4	29	22	9	8	27	65	68	19	13	3	37	31
Min 5	25	22	13	5	30	69	65	14	16	5	45	37
Min 6	40	27	10	12	38	70	70	26	19	5	49	38
Min 7	45	23	14	8	45	77	73	21	19	4	54	35
Min 8	40	29	11	8	40	81	73	27	17	5	50	37
Min 9	39	33	8	20	39	88	72	39	16	10	52	38
Min 10	35	37	14	22	40	94	74	34	20	7	59	39
Min 11	46	33	10	28	52	94	73	38	21	6	62	42
Min 12	53	36	13	34	55	95	76	46	23	7	65	46
Min 13	51	34	13	37	69	96	78	43	25	9	66	45
Min 14	47	32	13	31	78	96	76	44	21	8	70	51
Min 15	43	35	12	46	75	98	76	65	28	10	74	42
SUB. CONTROL												
Min 1	38	7	11	9	17	66	33	8	1	19	47	28
Min 2	40	12	13	18	12	73	30	7	1	23	55	28
Min 3	40	14	13	28	13	67	36	7	4	23	55	33
Min 4	47	11	12	33	18	76	36	15	1	22	55	37
Min 5	54	13	12	30	22	77	35	18	5	31	60	36
Min 6	50	15	16	30	21	73	39	22	4	29	63	34
Min 7	47	18	15	47	24	81	42	23	6	28	66	36
Min 8	55	25	16	56	37	82	46	26	6	28	65	37
Min 9	50	28	14	62	37	85	41	30	6	35	70	40
Min 10	47	30	20	63	50	84	47	37	7	33	59	32
Min 11	56	32	19	63	53	90	52	42	8	28	66	32
Min 12	51	37	19	70	57	91	51	67	5	21	77	33
Min 13	51	28	18	68	70	92	48	67	7	17	75	36
Min 14	60	36	22	76	74	97	61	79	9	27	69	32
Min 15	49	38	20	87	77	98	60	80	10	26	72	34

Table 4f : Summary of VAS intensity descriptive statistics for experiment 4 (100Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
NO TENS						
Min 1	22.58±19.25	18.50	370.45	0.09	0.46	-1.41
Min 2	25.92±20.23	23.00	409.36	0.17	0.44	-1.30
Min 3	29.33±22.37	24.00	500.42	0.32	0.48	-1.27
Min 4	29.25±20.59	24.50	424.02	0.10	0.39	-1.54
Min 5	31.58±20.51	26.00	420.81	0.19	0.45	-1.40
Min 6	34.17±19.92	32.50	396.88	0.57	0.23	-1.11
Min 7	35.67±21.14	34.50	446.97	0.40	0.07	-1.49
Min 8	36.58±20.72	32.00	429.72	0.28	0.43	-1.34
Min 9	37.83±21.20	38.50	449.42	0.65	0.02	-1.20
Min 10	42.17±20.73	42.00	429.79	0.62	-0.26	-0.72
Min 11	43.50±19.87	43.50	394.82	0.34	-0.30	-0.75
Min 12	44.58±21.42	44.50	456.81	0.82	-0.21	-0.57
Min 13	47.08±23.33	46.50	544.26	0.59	-0.20	-0.73
Min 14	48.50±23.69	44.00	563.36	0.63	-0.04	-0.38
Min 15	52.33±24.09	53.00	580.24	0.91	-0.24	-0.81
EXPT. CONTROL						
Min 1	23.92±21.80	16.50	475.17	0.04	1.08	0.11
Min 2	26.08±21.25	20.00	451.72	0.24	0.83	-0.34
Min 3	26.50±21.27	22.00	452.45	0.20	0.96	0.41
Min 4	27.58±20.86	24.50	435.17	0.11	1.04	0.39
Min 5	28.83±21.50	23.50	462.15	0.21	0.88	-0.22
Min 6	33.67±21.58	32.50	465.70	0.43	0.53	-0.54
Min 7	34.83±24.30	29.00	590.51	0.42	0.56	-0.79
Min 8	34.83±24.25	33.00	587.97	0.41	0.70	-0.18
Min 9	37.83±24.07	38.50	579.24	0.33	0.82	0.41
Min 10	39.58±25.21	36.00	635.54	0.33	0.98	0.69
Min 11	42.08±25.65	40.00	657.72	0.90	0.55	0.10
Min 12	45.75±25.54	46.00	652.20	0.96	0.31	-0.12
Min 13	47.17±26.28	44.00	690.51	0.92	0.32	-0.49
Min 14	47.25±27.95	45.50	780.93	0.74	0.27	-0.97
Min 15	50.33±27.45	44.50	753.33	0.67	0.10	-0.85
SUB. CONTROL						
Min 1	23.67±19.37	18.00	375.15	0.30	1.00	0.48
Min 2	26.00±21.08	20.50	444.18	0.22	1.17	0.96
Min 3	27.75±19.47	25.50	379.11	0.44	0.76	-0.10
Min 4	30.25±21.49	27.50	462.02	0.56	0.79	0.32
Min 5	32.75±21.54	30.50	463.84	0.46	0.81	0.05
Min 6	33.00±20.38	29.50	415.45	0.53	0.74	-0.03
Min 7	36.08±21.84	32.00	476.81	0.58	0.77	0.18
Min 8	39.92±21.79	37.00	474.63	0.94	0.40	-0.25
Min 9	41.50±22.55	38.50	508.45	0.86	0.43	0.01
Min 10	42.42±20.59	42.00	424.08	0.97	0.33	0.45
Min 11	45.08±22.77	47.00	518.63	0.96	0.27	-0.001
Min 12	48.25±25.93	51.00	672.57	0.96	-0.07	-0.82
Min 13	48.08±26.98	49.50	727.72	0.67	-0.04	-1.19
Min 14	53.50±27.39	60.50	750.09	0.58	-0.16	-1.17
Min 15	54.25±28.84	54.50	831.48	0.70	-0.04	-1.36

Table 4g : Raw VAS unpleasantness data for experiment 4 (100Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
NO TENS												
Min 1	15	3	2	2	21	8	33	3	0	3	58	30
Min 2	21	8	7	3	23	16	35	12	0	1	62	34
Min 3	25	11	4	4	23	33	53	15	7	4	71	38
Min 4	25	9	14	3	34	30	53	14	10	9	73	38
Min 5	32	12	12	4	37	43	55	20	16	10	76	36
Min 6	32	9	12	5	39	40	60	31	19	10	78	42
Min 7	27	11	13	6	34	42	66	34	28	21	79	39
Min 8	35	14	15	12	49	49	60	29	31	30	81	37
Min 9	32	14	12	6	50	49	64	33	32	38	84	55
Min 10	32	11	13	14	49	49	70	42	36	37	86	47
Min 11	35	15	16	19	49	59	74	52	45	38	82	43
Min 12	28	16	14	17	56	60	70	49	50	45	83	50
Min 13	26	17	18	15	74	64	82	54	48	48	91	45
Min 14	30	20	28	14	80	68	79	66	57	49	92	59
Min 15	36	20	16	30	90	79	81	78	58	58	90	54
EXPT. CONTROL												
Min 1	14	18	3	1	11	37	45	0	7	2	39	21
Min 2	16	20	5	1	22	28	47	7	15	1	39	20
Min 3	15	20	8	3	16	41	67	9	12	2	33	28
Min 4	22	21	7	2	20	49	69	12	15	5	22	38
Min 5	21	20	11	2	24	60	78	10	15	4	51	39
Min 6	14	25	11	1	33	59	72	14	20	7	51	44
Min 7	25	22	15	2	38	71	80	18	18	9	52	37
Min 8	27	18	13	5	25	64	82	22	19	13	58	38
Min 9	25	28	5	5	30	72	85	31	18	14	54	36
Min 10	24	27	9	6	32	76	90	29	20	11	68	44
Min 11	21	31	7	12	46	81	86	41	18	13	74	44
Min 12	26	30	10	14	64	79	94	44	24	12	77	61
Min 13	26	35	11	17	73	92	96	37	27	18	76	57
Min 14	32	36	12	21	78	93	94	40	27	20	78	61
Min 15	27	42	11	23	90	98	96	53	34	26	84	57
SUB. CONTROL												
Min 1	11	12	15	2	3	17	23	4	1	7	57	31
Min 2	23	13	13	4	3	21	26	5	5	22	69	33
Min 3	25	16	17	13	1	36	31	10	4	22	62	31
Min 4	36	18	18	14	1	34	32	9	8	32	66	38
Min 5	35	18	11	14	4	30	34	13	8	28	67	35
Min 6	31	18	10	17	4	28	31	12	13	45	71	38
Min 7	36	19	10	22	12	35	31	19	10	45	73	35
Min 8	32	21	7	22	14	43	34	27	10	50	79	36
Min 9	39	25	12	23	22	52	34	28	15	57	82	18
Min 10	41	26	18	31	27	50	41	37	11	43	67	28
Min 11	44	26	11	16	36	59	43	38	11	41	65	33
Min 12	38	31	12	39	48	71	48	65	14	44	75	41
Min 13	40	31	11	47	68	76	49	68	11	56	83	42
Min 14	43	25	15	55	74	65	52	82	13	53	70	38
Min 15	32	28	12	79	86	78	62	89	12	61	86	36

Table 4h : Summary of VAS unpleasantness descriptive statistics for experiment 4 (100Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
NO TENS						
Min 1	14.83±17.78	5.50	316.15	<0.01	1.50	1.96
Min 2	18.50±18.12	14.00	328.27	0.09	1.32	1.83
Min 3	24.00±21.46	19.00	460.73	0.09	1.10	0.59
Min 4	26.00±20.92	19.50	437.64	0.14	1.15	0.89
Min 5	29.42±21.35	26.00	455.90	0.34	0.94	0.48
Min 6	31.42±22.20	31.50	492.81	0.38	0.78	0.19
Min 7	33.33±21.62	31.00	467.33	0.34	0.96	0.65
Min 8	36.83±20.32	33.00	413.06	0.41	0.83	0.61
Min 9	39.08±22.77	35.50	518.63	0.80	0.37	-0.12
Min 10	40.50±22.49	39.50	505.73	0.45	0.53	0.21
Min 11	43.92±21.38	44.00	456.99	0.63	0.27	-0.50
Min 12	44.83±22.07	49.50	486.88	0.46	-0.03	-0.80
Min 13	48.50±25.96	48.00	673.91	0.47	0.16	-1.13
Min 14	53.50±25.49	58.00	649.91	0.60	-0.21	-1.20
Min 15	57.50±26.81	58.00	718.82	0.31	-0.31	-1.40
EXPT. CONTROL						
Min 1	16.50±15.93	12.50	253.91	0.09	0.77	-0.83
Min 2	18.42±14.41	18.00	207.72	0.45	0.67	-0.05
Min 3	21.17±18.71	15.50	349.97	0.07	1.46	2.26
Min 4	23.50±19.62	20.50	385.00	0.08	1.31	1.47
Min 5	27.92±24.00	20.50	576.08	0.17	1.01	0.07
Min 6	29.25±22.59	22.50	510.20	0.42	0.67	-0.70
Min 7	32.25±24.39	23.50	594.93	0.26	0.92	-0.06
Min 8	32.00±23.79	23.50	566.00	0.08	1.10	0.21
Min 9	33.58±25.09	29.00	629.72	0.22	0.98	0.29
Min 10	36.33±27.64	28.00	763.88	0.13	0.91	-0.33
Min 11	39.50±27.85	36.00	775.54	0.21	0.62	-1.00
Min 12	44.58±29.39	37.00	863.54	0.32	0.36	-1.40
Min 13	47.08±30.40	36.00	924.08	0.21	0.51	-1.34
Min 14	49.33±29.85	38.00	891.15	0.18	0.42	-1.51
Min 15	53.42±31.29	47.50	987.99	0.24	0.32	-1.53
SUB. CONTROL						
Min 1	15.25±15.97	11.50	255.11	0.01	1.82	3.76
Min 2	19.75±18.37	17.00	337.48	<0.01	1.87	4.48
Min 3	22.33±16.56	19.50	274.24	0.37	1.14	1.99
Min 4	25.50±17.80	25.00	317.00	0.37	0.85	1.12
Min 5	24.75±17.37	23.00	301.66	0.11	1.23	2.12
Min 6	26.50±18.66	23.00	348.27	0.24	1.23	1.78
Min 7	28.92±18.03	26.50	325.17	0.09	1.30	2.24
Min 8	31.25±19.88	29.50	395.11	0.33	1.20	2.02
Min 9	33.92±20.59	26.50	424.08	0.09	1.30	1.40
Min 10	35.00±14.97	34.00	224.00	0.84	0.54	0.79
Min 11	35.25±17.23	37.00	296.75	0.58	0.10	-0.55
Min 12	43.83±19.83	42.50	393.24	0.55	-0.02	-0.43
Min 13	48.50±23.35	48.00	545.36	0.63	-0.30	-0.68
Min 14	48.75±22.68	52.50	514.20	0.66	-0.30	-0.95
Min 15	55.08±29.52	61.50	871.36	0.10	-0.32	-1.62

Table 4i : Raw data for current intensity before pain induction in experiment 4 (100Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
EXPT. CONTROL												
Min 1	7	5	12	8	6	8	5	9	8	5	7	6
Min 2	7	5	12	9	7	8	5	9	8	5	7	6
Min 3	7	5	12	9	7	8	5	9	10	5	7	6
Min 4	10	6	11	9	7	8	6	9	10	5	7	6
Min 5	10	6	11	10	8	8	6	9	10	6	7	6
Min 6	10	8	11	10	8	11	6	9	10	6	7	6
Min 7	10	8	11	10	8	11	6	9	10	6	7	6
Min 8	10	8	11	10	8	11	7	9	10	6	7	6
Min 9	10	8	11	10	8	11	7	9	10	6	7	6
Min 10	11	8	11	10	8	11	7	9	10	7	7	6
Min 11	11	8	11	10	8	11	7	12	10	7	7	7
Min 12	11	8	11	10	9	11	8	12	10	7	7	7
Min 13	11	8	11	10	9	11	8	12	10	7	7	7
Min 14	11	8	11	10	9	11	8	12	10	7	7	7
Min 15	11	8	11	10	9	11	8	12	10	7	7	7
SUB. CONTROL												
Min 1	5	7	5	4	12	5	3	10	11	4	7	6
Min 2	6	11	5	4	12	5	3	12	11	6	10	6
Min 3	6	11	6	4	13	5	3	12	12	6	11	6
Min 4	6	11	6	5	13	6	3	12	13	6	11	6
Min 5	6	12	6	5	13	6	3	12	13	6	12	6
Min 6	7	12	6	5	13	6	3	12	15	8	13	8
Min 7	7	12	6	5	13	6	3	12	15	8	13	8
Min 8	8	12	6	5	13	6	3	12	15	8	13	8
Min 9	8	12	6	5	13	6	3	12	15	8	13	8
Min 10	8	12	6	5	15	6	8	12	15	10	13	8
Min 11	9	12	6	6	15	6	8	12	15	10	13	8
Min 12	9	12	6	6	15	6	8	12	15	10	13	8
Min 13	10	12	6	6	15	6	8	12	15	10	13	8
Min 14	10	12	6	6	15	6	8	12	15	10	13	8
Min 15	10	12	6	6	15	6	8	12	15	10	13	8

Table 4j : Summary of current intensity before pain induction descriptive statistics in experiment 4 (100Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
EXPT. CONTROL						
Min 1	7.17±2.04	7.00	4.15	0.13	1.12	1.71
Min 2	7.33±2.06	7.00	4.24	0.27	0.88	1.06
Min 3	7.50±2.19	7.00	4.82	0.39	0.65	-0.08
Min 4	7.83±1.95	7.50	3.79	0.50	0.19	-1.31
Min 5	8.08±1.89	8.00	3.54	0.09	0.15	-1.64
Min 6	8.50±1.93	8.50	3.73	0.16	-0.14	-1.59
Min 7	8.50±1.93	8.50	3.73	0.16	-0.14	-1.59
Min 8	8.58±1.83	8.50	3.36	0.31	-0.11	-1.48
Min 9	8.58±1.83	8.50	3.36	0.31	-0.11	-1.48
Min 10	8.75±1.81	8.50	3.29	0.22	0.007	-1.60
Min 11	9.08±1.93	9.00	3.72	0.04	0.13	-1.84
Min 12	9.25±1.81	9.50	3.29	0.22	-0.007	-1.60
Min 13	9.25±1.81	9.50	3.29	0.22	-0.007	-1.60
Min 14	9.25±1.81	9.50	3.29	0.22	-0.007	-1.60
Min 15	9.25±1.81	9.50	3.29	0.22	-0.007	-1.60
SUB. CONTROL						
Min 1	6.58±2.94	5.50	8.63	0.17	0.83	-0.54
Min 2	7.58±3.34	6.00	11.17	0.07	0.23	-1.78
Min 3	7.92±3.59	6.00	12.81	0.07	0.22	-1.78
Min 4	8.17±3.54	6.00	12.51	0.04	0.26	-1.66
Min 5	8.33±3.70	6.00	13.70	0.01	0.21	-1.87
Min 6	9.00±3.84	8.00	14.73	0.45	0.10	-1.34
Min 7	9.00±3.84	8.00	14.73	0.45	0.10	-1.34
Min 8	9.08±3.80	8.00	14.45	0.47	0.04	-1.26
Min 9	9.08±3.80	8.00	14.45	0.47	0.04	-1.26
Min 10	9.83±3.51	9.00	12.33	0.38	0.21	-1.36
Min 11	10.00±3.36	9.50	11.27	0.28	0.24	-1.35
Min 12	10.00±3.36	9.50	11.27	0.28	0.24	-1.35
Min 13	10.08±3.34	10.00	11.17	0.30	0.16	-1.33
Min 14	10.08±3.34	10.00	11.17	0.30	0.16	-1.33
Min 15	10.08±3.34	10.00	11.17	0.30	0.16	-1.33

Table 4k : Raw data for current intensity during pain induction in experiment 4 (100Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
EXPT. CONTROL												
Min 1	10	9	9	10	10	12	8	13	12	7	12	7
Min 2	11	9	9	10	10	12	8	13	12	7	12	7
Min 3	11	9	9	11	10	12	8	13	12	7	12	7
Min 4	12	9	9	11	10	12	9	13	12	8	12	7
Min 5	12	9	9	11	10	12	10	14	12	8	12	7
Min 6	12	10	9	11	10	12	10	14	12	8	12	7
Min 7	12	10	9	11	10	12	10	14	12	8	12	7
Min 8	12	10	8	10	10	12	10	14	12	8	13	7
Min 9	12	10	8	10	10	12	10	14	12	8	13	7
Min 10	12	11	8	10	10	12	10	14	12	10	13	7
Min 11	12	11	8	10	10	12	10	15	12	10	13	7
Min 12	13	11	8	10	10	12	10	15	12	10	13	7
Min 13	13	11	8	9	10	12	10	15	12	10	13	7
Min 14	13	11	8	9	10	12	10	15	12	10	13	7
Min 15	13	11	8	9	10	12	10	15	12	10	13	7
SUB. CONTROL												
Min 1	9	14	9	6	15	8	7	12	15	10	14	7
Min 2	9	14	9	6	19	8	8	12	15	11	14	7
Min 3	9	14	10	6	19	8	8	12	15	11	15	7
Min 4	9	14	10	6	19	8	8	12	15	11	15	7
Min 5	9	15	11	6	19	8	8	12	16	11	15	7
Min 6	10	15	11	6	19	8	8	14	16	11	15	7
Min 7	10	15	11	6	19	8	8	14	17	11	15	8
Min 8	10	15	12	6	19	8	8	14	17	11	15	8
Min 9	10	15	12	6	19	8	11	14	17	11	15	8
Min 10	10	15	12	6	19	8	11	14	17	11	15	8
Min 11	10	15	12	6	19	8	11	16	18	11	15	8
Min 12	10	15	12	6	19	8	10	16	17	11	18	8
Min 13	10	15	12	6	19	8	12	16	18	11	19	8
Min 14	10	15	12	6	19	8	12	16	19	11	19	8
Min 15	10	15	12	6	19	8	12	16	19	11	19	8

Table 4l : Summary of current intensity during pain induction descriptive statistics in experiment 4 (100Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
EXPT. CONTROL						
Min 1	9.92±2.02	10.00	4.08	0.42	-0.02	-1.14
Min 2	10.00±2.04	10.00	4.18	0.45	-0.15	-1.24
Min 3	10.08±2.06	10.50	4.26	0.39	-0.28	-1.29
Min 4	10.33±1.92	10.50	3.70	0.34	-0.29	-1.22
Min 5	10.50±2.02	10.50	4.09	0.68	-0.12	-0.55
Min 6	10.58±1.97	10.50	3.90	0.65	-0.23	-0.22
Min 7	10.58±1.97	10.50	3.90	0.65	-0.23	-0.22
Min 8	10.50±2.15	10.00	4.64	0.53	-0.07	-0.86
Min 9	10.50±2.15	10.00	4.64	0.53	-0.07	-0.86
Min 10	10.75±2.01	10.50	4.02	0.64	-0.32	-0.13
Min 11	10.83±2.07	10.50	4.70	0.71	0.06	0.33
Min 12	10.92±2.23	10.50	4.99	0.79	0.007	-0.06
Min 13	10.83±2.29	10.50	5.24	0.95	0.08	-0.35
Min 14	10.83±2.29	10.50	5.24	0.95	0.08	-0.35
Min 15	10.83±2.29	10.50	5.24	0.95	0.08	-0.35
SUB. CONTROL						
Min 1	10.50±3.34	9.50	11.18	0.21	0.21	-1.66
Min 2	11.00±3.88	10.00	15.09	0.47	0.69	-0.16
Min 3	11.17±3.93	10.50	15.42	0.59	0.60	-0.39
Min 4	11.17±3.93	10.50	15.42	0.59	0.60	-0.39
Min 5	11.42±4.08	10.50	16.63	0.55	0.46	-0.83
Min 6	11.67±4.10	11.00	16.79	0.61	0.28	-1.02
Min 7	11.83±4.11	11.00	16.88	0.54	0.32	-1.05
Min 8	11.92±4.10	11.50	16.81	0.65	0.25	-1.06
Min 9	12.17±3.93	11.50	15.42	0.92	0.16	-0.76
Min 10	12.17±3.93	11.50	15.42	0.92	0.16	-0.76
Min 11	12.42±4.17	11.50	17.36	0.72	0.13	-1.10
Min 12	12.50±4.36	11.50	19.00	0.49	0.13	-1.42
Min 13	12.83±4.51	12.00	20.33	0.46	0.09	-1.34
Min 14	12.92±4.62	12.00	21.36	0.36	0.12	-1.35
Min 15	12.92±4.62	12.00	21.36	0.36	0.12	-1.35

Appendix 5 : Experiment 5 - Tables

Figures XIV, XV and XVI in text (Chapter 12)
Tables 5a, 5b, 5c and 5d in text (Chapter 12)

Table 5e : Simple main effects for experiment 5 VAS pain intensity scores (5Hz TENS)

A = group

b = time b1 = min 1
b2 = min 2.....

Critical value = 3.00-3.40
* = significant result $p \leq 0.05$

	Mean Square (MS)	F value
A at b1 :	63.5278	1.05
A at b2 :	13	0.21
A at b3 :	18.75	0.31
A at b4 :	2.25	0.04
A at b5 :	37.4444	0.62
A at b6 :	118.0278	1.95
A at b7 :	71.3611	1.18
A at b8 :	148.7778	2.46
A at b9 :	243.3611	4.02*
A at b10 :	303.8611	5.02*
A at b11 :	320.4444	5.30*
A at b12:	459.6944	7.60*
A at b13 :	371.5833	6.14*
A at b14 :	471.1944	7.79*
A at b15 :	382.1111	6.32*

Table 5f : Simple main effects for experiment 5 VAS pain unpleasantness scores (5Hz TENS)

A = group

b = time b1 = min 1
b2 = min 2.....

Critical value = 3.00 - 3.40
* = significant result $p \leq 0.05$

	Mean Square (MS)	F value
A at b1 :	29.25	0.19
A at b2 :	6.7778	0.04
A at b3 :	17.5278	0.16
A at b4 :	24.6944	0.16
A at b5 :	27.25	0.18
A at b6 :	101.6944	0.67
A at b7 :	73.4444	0.48
A at b8 :	238.7778	1.57
A at b9 :	290.25	1.91
A at b10 :	482.6944	3.18*
A at b11 :	343.5833	2.27
A at b12:	444.1111	2.93
A at b13 :	503.0278	3.32*
A at b14 :	436.3611	2.88
A at b15 :	713.0278	4.70*

Table 5g : ANOVA Table for TENS current intensity (mA) before pain induction in experiment 5 (5Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	5.88	1	5.88	0.05	0.831
Error (Within + Residual)	1353.19	11	123.02		
Effect of Time					
Time	194.71	14	13.91	8.90	< 0.001
Error (Within + Residual)	240.63	154	1.56		
Interaction (Condition x Time)					
Condition x Time	12.37	14	0.88	1.30	0.212
Error (Within + Residual)	104.56	154	0.68		

Table 5h : ANOVA Table for TENS current intensity (mA) during pain induction in experiment 5 (5Hz TENS)

	SS	d.f.	MS	F	p
Effect of Condition					
Condition	90.00	1	90.00	0.33	0.575
Error (Within + Residual)	2958.33	11	268.94		
Effect of Time					
Time	166.92	14	11.92	6.34	< 0.001
Error (Within + Residual)	289.48	154	1.88		
Interaction (Condition x Time)					
Condition x Time	9.25	14	0.66	0.56	0.892
Error (Within + Residual)	181.42	154	1.18		

Table 5i : Raw VAS intensity data for experiment 5 (5Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
NO TENS												
Min 1	10	7	21	32	18	50	6	38	40	12	31	21
Min 2	21	14	23	34	27	51	7	39	41	14	34	19
Min 3	22	16	32	37	28	57	9	44	36	15	37	24
Min 4	28	10	36	38	38	59	10	46	46	21	40	26
Min 5	24	8	37	41	47	65	11	43	46	24	42	29
Min 6	30	9	35	47	43	63	16	47	52	26	42	35
Min 7	32	12	40	49	52	65	15	48	41	28	46	39
Min 8	35	12	39	52	50	66	15	48	40	36	49	47
Min 9	37	19	41	52	55	67	17	48	50	44	55	45
Min 10	36	24	46	53	58	69	16	53	48	47	56	53
Min 11	36	25	45	64	53	73	20	57	55	55	58	55
Min 12	40	27	43	69	54	79	22	63	50	58	65	56
Min 13	45	36	45	75	54	81	22	55	51	62	66	56
Min 14	60	34	45	74	61	81	21	58	57	66	68	58
Min 15	69	39	45	78	56	80	23	59	57	67	72	64
EXPT. CONTROL												
Min 1	32	11	19	26	25	53	18	41	35	18	29	33
Min 2	36	8	18	28	31	52	12	37	34	17	33	36
Min 3	38	5	20	34	33	53	28	38	31	19	35	38
Min 4	35	7	22	37	27	57	18	38	30	23	37	38
Min 5	34	11	24	37	32	65	23	39	28	25	39	44
Min 6	41	13	23	45	35	64	25	41	27	29	44	41
Min 7	52	15	25	48	36	64	27	42	28	33	41	46
Min 8	45	17	25	56	37	69	28	42	35	35	46	53
Min 9	54	18	26	63	38	73	29	44	36	34	53	55
Min 10	68	25	26	64	40	71	30	45	35	36	55	59
Min 11	59	25	25	67	45	77	34	45	39	38	59	63
Min 12	71	31	30	68	42	77	32	46	32	43	63	64
Min 13	77	22	30	73	42	74	33	47	39	47	66	67
Min 14	70	30	30	73	42	72	35	49	43	51	68	74
Min 15	80	29	30	74	38	73	43	48	42	54	71	77
SUB. CONTROL												
Min 1	21	12	15	30	35	53	6	32	39	18	28	18
Min 2	30	14	18	31	33	52	10	31	38	17	28	19
Min 3	33	16	21	34	33	57	14	32	37	19	29	21
Min 4	37	19	23	36	30	57	15	33	38	23	34	22
Min 5	38	21	24	36	38	57	13	36	37	25	34	25
Min 6	37	21	21	37	34	58	14	36	33	29	38	26
Min 7	39	26	23	39	40	63	15	36	40	33	45	24
Min 8	35	30	27	43	37	65	16	35	32	35	46	28
Min 9	38	34	27	45	39	61	16	38	32	34	48	29
Min 10	36	36	27	49	36	67	17	39	31	36	50	35
Min 11	39	40	26	53	36	68	17	44	32	38	50	41
Min 12	36	42	25	57	33	60	21	43	32	43	55	44
Min 13	42	47	28	66	29	61	20	43	34	47	61	46
Min 14	34	55	30	63	33	66	18	41	40	51	61	48
Min 15	41	60	32	65	43	67	18	42	37	54	63	55

Table 5j : Summary of VAS intensity descriptive statistics for experiment 5 (5Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
NO TENS						
Min 1	23.83±14.29	21.00	204.33	0.53	0.41	-0.93
Min 2	27.00±13.03	25.00	169.82	0.91	0.29	-0.65
Min 3	29.75±13.58	30.00	184.39	0.92	0.38	0.01
Min 4	33.17±14.76	37.00	217.97	0.69	-0.17	-0.37
Min 5	34.75±16.24	39.00	263.66	0.69	-0.08	-0.08
Min 6	37.08±15.27	38.50	233.17	0.95	-0.31	-0.09
Min 7	38.92±15.24	40.50	232.26	0.70	-0.39	-0.001
Min 8	40.75±15.25	43.50	232.57	0.33	-0.67	0.52
Min 9	44.17±14.46	46.50	209.06	0.33	-0.76	0.48
Min 10	46.58±14.79	50.50	218.63	0.28	-0.91	0.68
Min 11	49.67±15.57	55.00	242.42	0.27	-0.77	0.07
Min 12	52.17±16.84	55.00	283.42	0.88	-0.42	-0.31
Min 13	54.00±16.24	54.50	263.82	0.96	-0.23	0.31
Min 14	56.92±16.69	59.00	278.45	0.39	-0.91	0.85
Min 15	59.08±16.69	61.50	278.63	0.50	-0.90	0.55
EXPT. CONTROL						
Min 1	28.33±11.55	27.50	133.33	0.77	0.65	0.57
Min 2	28.50±12.54	32.00	157.18	0.48	-0.06	-0.22
Min 3	31.00±12.10	33.50	146.36	0.43	-0.55	1.37
Min 4	30.75±12.68	32.50	160.75	0.62	0.15	1.08
Min 5	33.42±13.44	33.00	180.63	0.45	0.86	2.18
Min 6	35.67±13.32	38.00	177.51	0.65	0.40	0.81
Min 7	38.50±13.69	39.00	187.36	0.97	0.11	-0.26
Min 8	41.25±14.78	39.50	218.39	0.97	0.22	-0.30
Min 9	43.75±16.43	41.00	269.84	0.90	0.21	-0.76
Min 10	46.17±16.62	42.50	276.15	0.37	0.23	-1.54
Min 11	48.00±16.85	45.00	283.82	0.61	0.19	-1.04
Min 12	49.92±17.57	44.50	308.81	0.10	0.26	-1.70
Min 13	51.42±19.14	47.00	366.45	0.35	0.01	-1.55
Min 14	53.08±17.42	50.00	303.54	0.08	-0.02	-1.79
Min 15	54.92±19.08	51.00	363.90	0.18	0.03	-1.76
SUB. CONTROL						
Min 1	25.58±13.15	24.50	172.99	0.85	0.58	0.22
Min 2	26.75±11.78	29.00	138.75	0.51	0.61	0.46
Min 3	28.83±11.82	30.50	139.61	0.20	1.05	1.85
Min 4	30.58±11.31	31.50	127.90	0.35	0.94	1.57
Min 5	32.00±11.29	35.00	127.45	0.36	0.52	1.28
Min 6	32.00±11.26	33.50	126.73	0.37	0.72	1.81
Min 7	35.25±12.49	37.50	156.02	0.48	0.57	1.26
Min 8	35.75±12.02	35.00	144.57	0.26	1.09	2.82
Min 9	36.75±11.34	36.00	128.57	0.78	0.43	1.35
Min 10	38.25±12.59	36.00	158.39	0.27	0.83	1.86
Min 11	40.33±13.07	39.50	170.79	0.83	0.38	1.18
Min 12	40.92±12.27	42.50	150.63	0.71	0.04	-0.76
Min 13	43.67±14.28	44.50	204.06	0.68	0.02	-0.78
Min 14	45.00±14.85	44.50	220.54	0.83	-0.20	-0.81
Min 15	48.08±15.05	48.50	226.45	0.52	-0.52	-0.38

Table 5k : Raw VAS unpleasantness data for experiment 5 (5Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
NO TENS												
Min 1	10	3	12	35	27	42	3	29	7	11	29	20
Min 2	16	3	15	36	33	45	3	31	13	12	31	24
Min 3	26	7	18	36	43	47	7	32	17	14	33	25
Min 4	17	2	19	37	51	67	6	34	19	18	34	27
Min 5	19	5	17	39	54	66	7	33	23	22	32	26
Min 6	20	4	21	42	50	73	9	33	26	23	33	28
Min 7	25	3	21	49	52	78	7	38	24	25	36	30
Min 8	30	8	22	59	55	79	8	39	26	34	38	36
Min 9	32	15	20	65	59	79	10	43	31	38	39	37
Min 10	36	19	26	66	70	83	16	45	37	42	43	45
Min 11	46	11	24	68	70	84	19	46	40	46	46	46
Min 12	47	26	26	76	69	85	16	47	29	52	49	50
Min 13	46	29	24	78	71	84	22	47	37	55	55	54
Min 14	57	31	24	81	76	86	17	48	41	59	65	55
Min 15	67	33	27	80	77	91	20	48	47	60	68	65
EXPT. CONTROL												
Min 1	38	1	10	22	36	44	6	21	14	15	26	27
Min 2	41	4	22	21	36	50	9	23	18	16	25	29
Min 3	39	1	28	23	34	52	9	24	22	18	27	33
Min 4	39	1	30	26	36	57	11	24	20	20	28	36
Min 5	38	4	34	27	37	70	12	27	22	23	30	38
Min 6	47	5	36	32	37	70	16	28	22	26	33	39
Min 7	44	5	43	36	35	75	14	32	27	28	35	40
Min 8	46	8	41	38	41	78	19	31	27	31	39	43
Min 9	59	10	47	45	46	79	19	29	26	29	43	45
Min 10	57	14	45	48	49	74	18	29	27	30	46	46
Min 11	62	14	42	49	48	79	16	33	33	35	50	48
Min 12	69	18	48	57	49	78	20	34	22	39	53	55
Min 13	75	16	47	68	45	82	21	35	29	46	55	61
Min 14	82	21	48	75	49	79	19	36	33	47	56	68
Min 15	89	23	52	77	50	77	20	36	35	49	59	73
SUB. CONTROL												
Min 1	27	3	13	31	31	32	4	15	24	12	24	19
Min 2	31	8	15	33	37	50	8	16	25	13	24	19
Min 3	28	5	19	35	37	46	11	17	25	14	25	24
Min 4	30	3	18	36	41	61	9	17	27	16	26	25
Min 5	30	8	22	39	31	67	11	18	27	18	28	25
Min 6	30	8	21	40	40	58	11	19	17	19	30	23
Min 7	31	15	22	41	42	64	11	20	25	22	33	26
Min 8	27	16	22	41	41	66	10	21	20	24	35	26
Min 9	29	21	22	43	42	70	12	23	22	28	38	28
Min 10	28	26	24	45	41	73	12	25	20	30	40	31
Min 11	39	32	25	4	45	74	14	25	23	35	43	34
Min 12	33	35	30	49	40	74	17	26	24	37	46	37
Min 13	35	42	29	51	43	78	12	27	26	40	48	39
Min 14	28	58	28	56	48	81	12	28	27	41	53	44
Min 15	44	58	30	58	47	79	11	27	21	47	60	51

Table 5l : Summary of VAS unpleasantness descriptive statistics for experiment 5 (5Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
NO TENS						
Min 1	19.00±13.14	16.00	172.72	0.39	0.35	-1.21
Min 2	21.83±13.48	20.00	181.79	0.56	0.12	-1.04
Min 3	25.42±13.22	25.50	174.81	0.73	0.11	-1.01
Min 4	27.58±18.45	23.00	340.45	0.49	0.79	0.59
Min 5	28.58±17.88	24.50	319.54	0.47	0.84	0.51
Min 6	30.17±18.53	27.00	343.42	0.44	1.00	1.62
Min 7	32.33±20.47	27.50	418.97	0.51	0.81	1.13
Min 8	36.17±20.57	35.00	423.24	0.57	0.61	0.43
Min 9	39.00±20.42	37.50	417.09	0.65	0.56	-0.09
Min 10	44.00±20.30	42.50	412.18	0.47	0.56	-0.21
Min 11	45.50±21.27	46.00	452.27	0.45	0.15	-0.23
Min 12	47.67±21.25	48.00	451.70	0.53	0.29	-0.66
Min 13	50.17±20.32	50.50	412.88	0.62	0.23	-0.86
Min 14	53.33±22.14	56.00	490.06	0.85	-0.17	-0.91
Min 15	56.92±22.17	62.50	491.36	0.77	0.30	-0.88
EXPT. CONTROL						
Min 1	21.67±13.25	21.50	175.51	0.94	0.17	-0.81
Min 2	24.50±13.04	22.50	170.09	0.90	0.46	0.09
Min 3	25.83±13.38	25.50	179.06	0.95	0.02	0.74
Min 4	27.33±14.32	27.00	204.97	0.89	0.21	1.08
Min 5	30.17±16.30	28.50	265.79	0.23	1.00	2.91
Min 6	32.58±16.22	32.50	262.99	0.53	0.73	2.06
Min 7	34.50±17.14	35.00	293.73	0.27	0.72	2.62
Min 8	36.83±16.98	38.50	288.33	0.22	0.89	2.95
Min 9	39.75±18.60	44.00	345.84	0.63	0.48	0.64
Min 10	40.25±17.15	45.50	294.20	0.62	0.23	-0.09
Min 11	42.42±18.15	45.00	329.36	0.63	0.26	0.47
Min 12	45.17±19.16	48.50	367.06	0.66	0.32	-0.79
Min 13	48.33±20.89	46.50	436.24	0.92	0.04	-0.89
Min 14	51.08±21.61	48.50	466.99	0.54	0.003	-1.17
Min 15	53.33±22.38	51.00	500.97	0.67	0.003	-1.09
SUB. CONTROL						
Min 1	19.58±10.22	21.50	104.45	0.38	-0.38	-1.12
Min 2	23.25±12.69	21.50	161.11	0.50	0.74	0.14
Min 3	23.83±11.66	24.50	135.97	0.98	0.31	-0.18
Min 4	25.75±15.46	25.50	239.11	0.58	0.88	1.41
Min 5	27.00±15.31	26.00	234.36	0.05	1.62	3.97
Min 6	26.33±14.17	22.00	200.79	0.39	0.97	0.88
Min 7	29.33±14.40	25.50	207.33	0.29	1.26	2.04
Min 8	29.08±14.94	25.00	223.17	0.11	1.40	2.53
Min 9	31.50±15.20	28.00	231.00	0.05	1.52	3.07
Min 10	32.92±15.66	29.00	245.36	0.08	1.53	3.41
Min 11	36.33±15.43	34.50	238.06	0.32	1.16	2.49
Min 12	37.33±14.65	36.00	214.61	0.23	1.35	2.99
Min 13	39.17±16.32	39.50	266.33	0.41	0.90	2.43
Min 14	42.00±18.70	42.50	349.82	0.63	0.48	0.36
Min 15	44.42±19.17	47.00	367.36	0.84	-0.12	-0.25

Table 5m : Raw data for current intensity before pain induction in experiment 5 (5Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
EXPT. CONTROL												
Min 1	4	8	10	13	19	15	5	6	9	12	7	9
Min 2	4	8	10	13	25	21	5	6	9	12	7	9
Min 3	4	8	10	13	25	21	5	7	9	12	7	11
Min 4	4	8	10	13	30	21	5	7	9	12	7	11
Min 5	6	8	10	13	30	21	5	7	9	12	7	12
Min 6	6	10	13	18	30	21	5	7	9	12	7	12
Min 7	6	10	13	18	30	21	5	7	9	12	7	12
Min 8	6	10	13	18	30	21	5	7	9	12	7	12
Min 9	6	10	13	18	30	21	5	7	9	12	7	12
Min 10	6	10	13	18	30	21	5	7	9	12	7	12
Min 11	6	10	13	18	30	24	5	7	9	12	7	12
Min 12	6	10	13	18	30	24	5	7	9	12	7	12
Min 13	6	10	13	18	30	24	5	7	9	12	7	12
Min 14	6	10	13	18	30	24	5	7	9	12	7	12
Min 15	6	10	13	18	30	24	5	7	9	12	7	12
SUB. CONTROL												
Min 1	12	13	10	8	20	14	6	6	8	12	8	10
Min 2	12	14	11	8	20	14	6	6	8	12	8	10
Min 3	12	14	11	8	20	14	6	6	8	14	9	11
Min 4	12	14	11	10	20	14	6	6	8	14	9	11
Min 5	12	14	11	10	24	14	6	6	8	14	9	11
Min 6	13	14	11	10	24	14	6	6	8	14	9	11
Min 7	13	14	11	10	24	19	6	6	8	14	9	11
Min 8	13	14	13	10	24	19	6	6	8	14	9	11
Min 9	13	14	13	10	24	19	6	6	8	14	9	11
Min 10	13	14	13	10	24	19	6	6	8	14	9	11
Min 11	13	14	13	10	24	19	6	6	8	14	9	11
Min 12	13	14	13	10	24	19	6	6	8	14	9	11
Min 13	13	14	13	10	24	19	6	6	8	14	9	11
Min 14	13	14	13	10	24	19	6	6	8	14	9	11
Min 15	13	14	13	10	24	19	6	6	8	14	9	11

Table 5n : Summary of current intensity before pain induction descriptive statistics in experiment 5 (5Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
EXPT. CONTROL						
Min 1	9.75±4.37	9.00	19.11	0.65	0.79	0.32
Min 2	10.75±6.35	9.00	40.39	0.04	1.40	1.40
Min 3	11.00±6.27	9.50	39.27	0.06	1.34	1.35
Min 4	11.42±7.35	9.50	54.08	0.01	1.76	3.15
Min 5	11.67±7.19	9.50	51.70	<0.01	1.83	3.32
Min 6	12.50±7.30	11.00	53.36	0.06	1.41	1.88
Min 7	12.50±7.30	11.00	55.36	0.06	1.41	1.88
Min 8	12.50±7.30	11.00	55.36	0.06	1.41	1.88
Min 9	12.50±7.30	11.00	55.36	0.06	1.41	1.88
Min 10	12.50±7.30	11.00	55.36	0.06	1.41	1.88
Min 11	12.75±7.66	11.00	58.75	0.05	1.33	1.15
Min 12	12.75±7.66	11.00	58.75	0.05	1.33	1.15
Min 13	12.75±7.66	11.00	58.75	0.05	1.33	1.15
Min 14	12.75±7.66	11.00	58.75	0.05	1.33	1.15
Min 15	12.75±7.66	11.00	58.75	0.05	1.33	1.15
SUB. CONTROL						
Min 1	10.58±3.96	10.00	15.72	0.24	1.14	1.74
Min 2	10.75±4.02	10.50	16.20	0.31	0.98	1.21
Min 3	11.08±4.05	11.00	16.45	0.41	0.74	0.67
Min 4	11.25±3.96	11.00	15.66	0.47	0.70	0.91
Min 5	11.58±4.83	11.00	23.36	0.06	1.49	3.49
Min 6	11.67±4.85	11.00	23.52	0.07	1.41	3.24
Min 7	12.08±5.26	11.00	27.72	0.28	1.10	1.22
Min 8	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 9	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 10	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 11	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 12	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 13	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 14	12.25±5.26	12.00	27.66	0.33	1.00	1.05
Min 15	12.25±5.26	12.00	27.66	0.33	1.00	1.05

Table 5o : Raw data for current intensity during pain induction in experiment 5 (5Hz TENS)

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
EXPT. CONTROL												
Min 1	10	14	12	18	38	16	5	9	12	15	9	11
Min 2	10	14	12	18	38	16	5	9	12	15	9	11
Min 3	10	14	12	18	40	16	8	9	12	15	10	11
Min 4	10	14	17	18	40	16	8	10	12	15	10	11
Min 5	12	14	17	19	40	16	8	10	12	15	10	12
Min 6	12	13	17	19	40	16	8	10	12	15	11	12
Min 7	12	13	17	19	40	16	8	10	12	15	11	12
Min 8	12	13	17	19	40	16	8	11	12	15	12	12
Min 9	12	13	17	19	40	20	8	11	12	15	12	12
Min 10	12	13	17	19	40	20	8	11	12	16	12	12
Min 11	12	13	17	19	40	20	8	12	12	16	12	12
Min 12	12	13	17	19	40	20	8	12	12	16	12	12
Min 13	12	13	17	19	40	20	10	12	12	16	12	12
Min 14	12	13	17	19	40	20	10	12	12	16	12	12
Min 15	12	13	17	19	40	20	10	12	12	16	12	12
SUB. CONTROL												
Min 1	16	14	12	17	26	26	6	10	8	17	11	13
Min 2	25	16	12	17	26	26	6	10	8	17	11	13
Min 3	25	16	12	13	32	26	6	10	8	17	11	14
Min 4	26	16	15	13	32	26	6	11	8	18	11	14
Min 5	26	16	15	13	32	26	6	11	8	18	11	14
Min 6	26	16	15	13	32	26	6	11	8	18	11	14
Min 7	29	16	15	13	32	26	6	11	8	18	14	14
Min 8	29	16	15	13	32	27	6	11	8	18	14	14
Min 9	29	16	15	13	32	27	6	11	8	19	14	14
Min 10	29	16	15	13	32	27	6	12	8	19	16	15
Min 11	20	16	15	13	32	27	6	12	8	19	16	15
Min 12	20	16	15	13	32	27	6	12	8	20	16	15
Min 13	25	16	15	13	32	27	6	12	8	20	16	15
Min 14	24	16	15	13	32	27	6	12	8	20	16	15
Min 15	24	16	15	13	32	27	6	12	8	20	16	15

Table 5p : Summary of current intensity during pain induction descriptive statistics in experiment 5 (5Hz TENS)

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
EXPT. CONTROL						
Min 1	14.08±8.32	12.00	69.17	<0.01	2.39	7.03
Min 2	14.08±8.32	12.00	69.19	<0.01	2.39	7.03
Min 3	14.58±8.54	12.00	72.99	<0.01	2.75	8.43
Min 4	15.08±8.47	13.00	71.72	<0.01	2.63	7.93
Min 5	15.42±8.37	13.00	70.08	<0.01	2.61	7.85
Min 6	15.42±8.33	12.50	69.54	<0.01	2.66	8.02
Min 7	15.42±8.33	12.50	69.54	<0.01	2.66	8.02
Min 8	15.58±8.24	12.50	67.90	<0.01	2.70	8.27
Min 9	15.92±8.34	12.50	69.54	<0.01	2.48	7.10
Min 10	16.00±8.33	12.50	69.45	<0.01	2.45	7.01
Min 11	16.08±8.28	12.50	68.63	<0.01	2.47	7.12
Min 12	16.08±8.28	12.50	69.63	<0.01	2.47	7.12
Min 13	16.25±8.12	12.50	66.02	<0.01	2.60	7.60
Min 14	16.25±8.12	12.50	66.02	<0.01	2.60	7.60
Min 15	16.25±8.12	12.50	66.02	<0.01	2.60	7.60
SUB. CONTROL						
Min 1	14.67±6.29	13.50	39.51	0.31	0.80	0.14
Min 2	15.58±6.95	14.50	48.26	0.29	0.47	-1.00
Min 3	15.83±7.93	13.50	62.88	0.29	0.92	-0.001
Min 4	16.33±7.90	14.50	64.42	0.37	0.80	-0.16
Min 5	16.33±7.90	14.50	62.42	0.37	0.80	-0.16
Min 6	16.33±7.90	14.50	62.42	0.37	0.80	-0.16
Min 7	16.83±8.13	14.50	66.15	0.29	0.77	-0.31
Min 8	16.92±8.24	14.50	67.90	0.25	0.76	-0.43
Min 9	17.00±8.26	14.50	68.18	0.30	0.72	-0.50
Min 10	17.33±8.12	15.50	65.88	0.35	0.64	-0.44
Min 11	16.58±7.32	15.50	53.54	0.46	0.80	0.75
Min 12	16.67±7.35	15.50	54.06	0.48	0.76	0.61
Min 13	17.08±7.69	15.50	59.17	0.57	0.59	-0.16
Min 14	17.00±7.60	15.50	57.82	0.62	0.61	-0.16
Min 15	17.00±7.60	15.50	57.82	0.62	0.61	-0.16

Appendix 6 : Experiment 6 - Tables

Figures XVII, XVIII and XIX in text (Chapter 13)
Tables 6a and 6b are shown in text (Chapter 13)

Table 6c : ANOVA table for mean TENS current intensities before pain induction in experiment 6

TENS CURRENT (BEFORE PAIN)	SS	d.f.	MS	F	p
Effect of frequency					
Frequency	451.14	1	451.14	7.38	0.02
Error (Within + Residual)	672.03	11	61.09		
Effect of Time					
Minute	147.60	14	10.54	7.79	< 0.001
Error (Within + Residual)	208.47	154	1.35		
Interaction					
Frequency x Minute	5.16	14	0.37	0.67	0.805
Error (Within + Residual)	85.18	154	0.55		

Table 6d : Simple main effects for mean TENS current intensities before pain induction in experiment 6

A = experimental group (high frequency or low frequency TENS)

b = time b1 = min 1
b2 = min 2.....

Critical value = 3.92-4.84
* = significant result $p \leq 0.05$

	Mean Square (MS)	F value
A at b1 :	28.17	6.14*
A at b2 :	18.375	4.01*
A at b3 :	18.375	4.01*
A at b4 :	26.04	5.68*
A at b5 :	32.67	7.12*
A at b6 :	35.04	7.64*
A at b7 :	32.67	7.12*
A at b8 :	30.375	7.64*
A at b9 :	26.04	5.68*
A at b10 :	30.375	6.62*
A at b11 :	42.67	9.30*
A at b12:	37.50	8.18*
A at b13 :	32.67	7.12*
A at b14 :	32.67	7.12*
A at b15 :	2.67	7.12*

Table 6e : ANOVA table for mean TENS current intensities during pain induction in experiment 6

TENS CURRENT (DURING PAIN)	SS	d.f.	MS	F	p
Effect of frequency					
Frequency	893.02	1	893.02	7.21	0.021
Error (Within + Residual)	1362.48	11	123.86		
Effect of Time					
Minute	380.33	14	27.17	4.47	< 0.001
Error (Within + Residual)	936.73	154	6.08		
Interaction					
Frequency x Minute	65.77	14	4.70	1.34	0.188
Error (Within + Residual)	538.23	154	3.50		

Table 6f : Simple main effects for mean TENS current intensities during pain induction in experiment 6

A = experimental group (high frequency or low frequency TENS)

b = time b1 = min 1
b2 = min 2.....

Critical value = 3.92-4.84
* = significant result $p \leq 0.05$

	Mean Square (MS)	F value
A at b1 :	42.67	3.70
A at b2 :	35.04	3.04
A at b3 :	26.04	2.26
A at b4 :	28.17	2.44
A at b5 :	28.17	2.44
A at b6 :	42.67	3.70
A at b7 :	50.04	4.43*
A at b8 :	50.04	4.43*
A at b9 :	60.17	5.22*
A at b10 :	54.00	4.69*
A at b11 :	70.04	6.08*
A at b12:	96.00	8.33*
A at b13 :	126.04	10.94*
A at b14 :	117.04	10.16*
A at b15 :	130.67	11.34*

Table 6g : Raw VAS intensity data for experiment 6

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
NO TENS												
Min 1	16	37	18	12	7	28	28	18	46	8	44	12
Min 2	12	41	20	11	5	20	34	29	47	16	38	10
Min 3	14	42	29	16	14	19	39	34	60	19	31	14
Min 4	13	47	33	22	13	19	42	40	59	18	41	15
Min 5	19	45	33	20	16	25	44	38	62	23	39	17
Min 6	23	55	26	21	18	28	45	36	59	29	40	18
Min 7	25	60	33	26	14	29	45	35	65	45	37	19
Min 8	25	59	36	30	16	29	42	38	65	65	39	18
Min 9	24	49	30	35	15	35	45	41	72	78	47	20
Min 10	28	55	41	38	26	31	45	44	75	83	45	28
Min 11	28	52	41	38	22	25	44	45	71	93	53	23
Min 12	33	59	34	42	33	25	46	45	76	98	50	23
Min 13	39	53	33	50	26	24	49	44	81	100	35	25
Min 14	36	54	41	49	30	27	57	41	79	100	42	34
Min 15	39	54	38	48	42	29	53	46	89	100	50	35
HF (100Hz) TENS												
Min 1	13	26	17	17	5	15	26	21	64	34	24	10
Min 2	13	27	19	19	8	16	42	23	69	43	28	8
Min 3	18	32	19	27	11	19	56	26	82	52	30	7
Min 4	16	28	20	30	11	20	43	25	84	60	33	8
Min 5	20	26	25	32	15	16	39	26	90	57	31	11
Min 6	19	31	20	33	14	18	39	26	89	69	32	10
Min 7	19	32	29	34	19	20	35	26	91	73	33	9
Min 8	18	27	26	31	25	16	40	27	92	74	42	15
Min 9	22	35	30	38	29	17	44	28	90	84	35	13
Min 10	21	27	30	36	28	19	46	29	93	91	36	17
Min 11	25	31	41	37	38	25	44	28	94	91	38	11
Min 12	28	28	36	37	60	26	45	30	96	93	32	13
Min 13	26	35	39	39	38	22	43	31	96	98	46	15
Min 14	27	30	40	47	64	25	46	30	95	99	45	16
Min 15	30	30	34	49	66	19	41	30	96	100	42	16
LF (5Hz) TENS												
Min 1	15	22	19	6	3	39	38	9	25	3	20	6
Min 2	22	15	14	5	4	38	43	15	47	4	31	9
Min 3	23	18	22	6	15	51	40	20	53	7	27	10
Min 4	24	20	21	6	21	53	41	21	55	14	30	13
Min 5	23	23	28	9	18	72	42	25	63	19	35	12
Min 6	29	21	27	10	18	74	40	29	57	24	40	15
Min 7	31	22	29	11	24	75	42	30	58	26	36	15
Min 8	22	25	33	11	26	76	40	30	66	32	47	18
Min 9	21	19	29	11	31	75	40	31	74	35	35	22
Min 10	21	25	25	11	49	77	45	30	76	41	33	28
Min 11	24	23	33	17	36	71	45	31	77	49	32	31
Min 12	23	23	33	22	44	73	44	31	78	59	42	33
Min 13	28	31	35	25	50	72	40	33	80	70	39	37
Min 14	28	29	31	27	62	72	45	33	77	75	52	39
Min 15	31	30	39	30	59	76	40	34	83	83	45	38

Table 6h : Summary of VAS intensity descriptive statistics for experiment 6

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
NO TENS						
Min 1	22.83±13.61	18.00	185.24	0.24	0.64	-0.94
Min 2	23.58±13.83	20.00	191.17	0.47	0.39	-1.24
Min 3	27.58±14.39	24.00	20717	0.08	1.04	0.73
Min 4	30.17±15.48	27.50	239.61	0.25	0.45	-1.06
Min 5	31.75±14.21	29.00	202.02	0.30	0.79	0.05
Min 6	33.17±13.97	28.50	195.06	0.26	0.77	-0.57
Min 7	36.08±15.47	34.00	239.36	0.63	0.61	-0.21
Min 8	38.50±16.83	37.00	283.18	0.33	0.50	-0.81
Min 9	40.92±19.18	38.00	367.72	0.44	0.75	0.13
Min 10	44.92±18.20	42.50	331.36	0.06	1.16	0.65
Min 11	44.58±21.02	42.50	441.72	0.18	1.16	1.37
Min 12	47.00±21.84	43.50	476.91	0.10	1.32	1.62
Min 13	46.58±23.12	41.50	534.45	0.04	1.40	1.63
Min 14	49.17±21.33	41.50	455.06	0.04	1.50	2.01
Min 15	51.92±21.36	47.50	456.08	0.01	1.56	1.78
HF TENS						
Min 1	22.67±15.23	19.00	232.06	0.02	1.94	4.96
Min 2	26.25±17.64	21.00	311.36	0.07	1.40	2.07
Min 3	31.58±21.61	26.50	467.17	0.08	1.31	1.47
Min 4	31.50±21.82	26.50	476.10	0.06	1.48	2.12
Min 5	32.33±21.93	26.00	480.79	<0.01	1.91	4.03
Min 6	33.33±23.26	28.50	545.51	0.01	1.62	2.21
Min 7	35.00±23.60	30.50	556.73	<0.01	1.66	2.35
Min 8	36.08±23.75	27.00	564.08	<0.01	1.65	2.08
Min 9	38.75±24.19	32.50	584.93	<0.01	1.48	1.43
Min 10	39.42±25.83	29.50	667.17	<0.01	1.64	1.60
Min 11	41.92±25.27	37.50	638.45	<0.01	1.46	1.49
Min 12	43.67±26.30	34.00	691.88	0.01	1.32	0.79
Min 13	44.00±26.30	38.50	691.82	<0.01	1.52	1.53
Min 14	47.00±26.58	42.50	706.73	0.05	1.15	0.44
Min 15	46.0827.65	37.50	764.26	0.04	1.17	0.39
LF TENS						
Min 1	17.08±12.54	17.00	157.17	0.25	0.63	-0.59
Min 2	20.58±15.51	15.00	240.63	0.16	0.61	-1.11
Min 3	24.33±15.90	21.00	252.79	0.18	0.84	-0.34
Min 4	26.58±15.48	21.00	239.54	0.13	0.89	-0.12
Min 5	30.75±19.48	24.00	379.29	0.07	1.23	0.78
Min 6	32.00±18.37	28.00	337.64	0.18	1.24	1.34
Min 7	33.25±18.01	29.50	324.20	0.15	1.29	1.67
Min 8	35.50±19.21	31.00	369.18	0.22	1.10	0.69
Min 9	33.58±22.05	31.00	486.08	0.15	0.88	0.68
Min 10	38.42±20.64	31.50	426.08	0.14	0.98	0.28
Min 11	39.08±18.56	32.50	344.63	0.07	1.16	0.59
Min 12	42.08±18.97	37.50	359.90	0.11	0.89	-0.24
Min 13	45.00±18.73	38.00	350.72	0.04	0.98	-0.52
Min 14	47.50±19.45	42.00	378.27	0.07	0.50	-1.50
Min 15	49.00±20.74	39.50	430.00	0.01	0.90	-0.91

Table 6i : Raw VAS unpleasantness data for experiment 6

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
NO TENS												
Min 1	10	26	22	5	16	27	33	8	59	9	33	5
Min 2	9	31	28	6	22	21	38	19	63	14	26	8
Min 3	17	36	28	9	29	16	50	31	59	18	34	9
Min 4	18	41	28	14	35	19	54	28	60	17	32	9
Min 5	23	43	23	17	32	21	53	30	70	23	28	10
Min 6	27	40	24	17	37	23	50	36	74	30	51	7
Min 7	33	50	25	22	39	30	54	37	71	46	45	9
Min 8	33	54	27	26	44	26	63	36	74	60	46	10
Min 9	38	52	34	29	47	34	60	36	80	75	51	10
Min 10	39	60	25	28	70	32	67	45	77	81	44	10
Min 11	41	61	23	32	84	38	62	38	78	95	56	9
Min 12	49	57	27	30	90	35	66	45	76	98	56	12
Min 13	47	58	25	35	97	41	76	56	85	99	46	15
Min 14	49	55	30	39	98	42	71	59	84	100	50	9
Min 15	54	59	28	42	100	41	72	63	90	100	49	15
HF (100Hz) TENS												
Min 1	6	16	11	6	13	17	40	19	64	13	19	4
Min 2	12	14	14	9	16	17	54	19	74	27	26	4
Min 3	15	21	12	13	24	17	61	21	88	38	32	4
Min 4	17	19	20	19	27	20	50	24	87	51	34	4
Min 5	20	23	20	24	35	23	51	23	91	48	32	4
Min 6	24	27	22	26	43	28	48	25	92	71	34	5
Min 7	26	23	22	26	58	31	47	28	92	82	31	4
Min 8	27	26	23	33	66	35	42	30	94	88	44	4
Min 9	29	24	23	30	71	34	46	34	94	90	31	6
Min 10	33	30	26	35	72	39	45	36	96	91	25	7
Min 11	38	31	23	39	91	42	56	36	96	95	28	8
Min 12	41	30	24	43	94	34	54	39	95	95	46	8
Min 13	44	35	18	46	97	44	58	41	97	97	57	7
Min 14	46	33	25	52	100	44	68	40	97	99	51	8
Min 15	45	28	19	47	100	38	79	44	98	100	53	9
LF (5Hz) TENS												
Min 1	12	9	19	2	8	64	54	9	45	5	7	3
Min 2	21	13	23	3	9	75	54	18	53	7	26	6
Min 3	28	17	16	4	24	80	55	21	58	9	26	6
Min 4	30	17	14	5	23	81	61	25	63	15	37	5
Min 5	30	14	28	5	20	84	67	27	60	16	37	7
Min 6	36	15	25	7	30	82	73	28	68	25	22	6
Min 7	32	15	25	9	39	84	69	33	66	24	28	6
Min 8	35	20	23	6	40	84	79	33	74	30	25	9
Min 9	37	19	26	8	47	87	78	38	78	33	29	9
Min 10	45	17	20	8	68	81	84	34	78	32	29	8
Min 11	46	20	28	7	51	87	76	39	79	44	33	10
Min 12	43	20	25	6	57	82	78	40	85	61	36	8
Min 13	56	23	20	10	72	85	79	40	83	60	30	8
Min 14	61	33	22	12	54	88	85	41	89	71	34	11
Min 15	67	31	22	14	76	88	84	43	93	90	50	11

Table 6j : Summary of VAS unpleasantness descriptive statistics for experiment 6

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
NO TENS						
Min 1	21.08±15.85	19.00	251.36	0.09	1.22	1.73
Min 2	23.75±15.75	21.50	248.02	0.13	1.40	2.72
Min 3	28.00±15.50	28.50	240.18	0.44	0.69	-0.02
Min 4	29.58±15.85	28.00	251.17	0.44	0.74	-0.23
Min 5	31.08±16.76	25.50	280.81	0.09	1.31	1.57
Min 6	34.67±17.82	33.00	317.51	0.74	0.75	1.03
Min 7	38.42±16.40	38.00	268.81	>0.99	0.19	0.48
Min 8	41.58±18.66	40.00	348.08	0.91	0.15	-0.63
Min 9	45.50±19.75	42.50	389.91	0.75	0.24	0.04
Min 10	48.17±22.67	44.50	513.97	0.72	-0.03	-1.12
Min 11	51.42±25.84	48.50	667.72	0.92	0.16	-0.72
Min 12	53.42±25.95	52.50	673.17	0.95	0.26	-0.60
Min 13	56.67±27.40	51.50	750.79	0.64	0.27	-0.97
Min 14	57.17±27.23	52.50	741.61	0.79	0.14	-0.37
Min 15	59.42±27.20	56.50	740.08	0.70	0.18	-0.75
HF TENS						
Min 1	19.00±17.00	14.50	288.91	<0.01	2.04	4.29
Min 2	23.83±20.27	16.50	410.91	<0.01	1.81	2.88
Min 3	28.83±23.85	21.00	568.88	0.01	1.70	2.74
Min 4	31.00±22.21	22.00	493.27	0.02	1.61	2.94
Min 5	32.83±22.32	23.50	497.97	0.02	1.71	3.84
Min 6	37.08±23.76	27.50	564.63	0.05	1.32	1.71
Min 7	39.17±26.01	29.50	676.33	0.06	1.07	0.46
Min 8	42.67±26.89	34.00	723.15	0.15	0.92	0.19
Min 9	42.67±27.64	32.50	763.88	0.04	1.00	-0.04
Min 10	47.92±27.86	37.50	775.90	0.32	0.59	-0.69
Min 11	48.58±29.69	38.50	881.54	0.06	0.76	-0.71
Min 12	50.25±29.18	42.00	851.29	0.07	0.68	-0.64
Min 13	53.42±29.95	45.00	896.99	0.21	0.38	-0.66
Min 14	55.25±30.06	48.50	903.48	0.33	0.39	-0.77
Min 15	55.00±31.90	46.00	1017.64	0.26	0.35	1.18
LF TENS						
Min 1	19.75±21.69	9.00	470.39	<0.01	1.31	0.18
Min 2	25.69±22.88	19.50	523.51	0.04	1.19	0.43
Min 3	28.67±23.52	22.50	552.97	0.06	1.18	0.60
Min 4	31.33±24.59	24.00	604.79	0.12	0.96	-0.14
Min 5	32.92±24.96	27.50	622.81	0.19	0.98	0.03
Min 6	34.75±25.60	26.50	655.48	0.06	0.92	-0.43
Min 7	35.83±24.73	30.00	611.42	0.23	0.85	-0.26
Min 8	38.17±26.59	31.50	707.06	0.08	0.81	-0.62
Min 9	40.75±26.87	35.00	722.20	0.20	0.67	-0.74
Min 10	42.00±28.64	33.00	820.00	0.15	0.41	-0.48
Min 11	43.33±26.37	41.50	695.33	0.53	0.37	-0.86
Min 12	45.08±27.77	41.50	771.17	0.50	0.10	-1.27
Min 13	47.17±28.88	48.00	833.79	0.31	-0.002	-1.68
Min 14	50.08±28.83	47.50	831.17	0.38	0.09	-1.46
Min 15	55.75±31.08	58.50	966.20	0.23	-0.22	-1.68

Table 6k : Raw data for current intensity before pain induction in experiment 6

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
HF (100Hz) TENS												
Min 1	14	5	6	8	8	5	6	4	8	10	6	7
Min 2	15	6	6	9	10	5	6	5	7	13	5	7
Min 3	17	7	7	11	10	5	6	5	7	13	5	7
Min 4	17	7	7	11	10	5	7	5	7	13	5	7
Min 5	17	7	7	11	10	5	7	5	6	13	5	7
Min 6	17	7	7	11	10	5	7	5	6	13	5	7
Min 7	18	7	7	11	10	6	7	5	6	13	5	7
Min 8	19	7	7	11	10	6	7	5	6	13	5	7
Min 9	20	7	7	11	10	6	7	5	6	15	5	7
Min 10	20	7	7	11	10	7	7	5	6	15	5	7
Min 11	20	7	7	11	10	7	7	5	6	15	5	7
Min 12	21	7	7	11	10	8	8	5	6	15	5	7
Min 13	21	7	8	11	10	8	8	6	6	18	5	7
Min 14	21	7	8	11	10	8	8	6	6	18	5	7
Min 15	21	7	8	11	10	8	8	6	6	18	5	7
LF (5Hz) TENS												
Min 1	21	7	7	12	10	5	8	6	9	12	10	6
Min 2	21	7	7	12	12	5	8	6	9	12	10	6
Min 3	24	7	9	12	12	6	8	6	9	12	10	6
Min 4	25	7	9	15	12	7	8	6	9	12	10	6
Min 5	26	7	9	15	12	8	8	6	9	12	10	6
Min 6	26	7	9	15	12	8	9	6	9	12	10	6
Min 7	27	7	9	15	12	8	9	6	9	12	10	6
Min 8	27	7	9	15	12	8	9	6	9	12	10	6
Min 9	27	7	9	15	12	9	9	6	9	12	10	6
Min 10	28	7	9	15	12	9	9	6	9	12	10	7
Min 11	29	7	9	16	12	9	9	6	9	12	13	7
Min 12	29	7	9	16	12	9	9	6	9	12	13	7
Min 13	31	7	9	16	12	9	9	7	9	12	13	7
Min 14	31	7	9	16	12	9	9	7	9	12	13	7
Min 15	31	7	9	16	12	9	9	7	9	12	13	7

Table 6l : Summary of current intensity before pain induction descriptive statistics in experiment 6

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
HF TENS						
Min 1	7.25±2.70	6.50	7.29	0.08	1.48	2.79
Min 2	7.83±3.30	6.50	10.88	0.02	1.31	0.76
Min 3	8.33±3.73	7.00	13.88	0.02	1.36	1.35
Min 4	8.42±3.68	7.00	13.54	0.02	1.35	1.42
Min 5	8.33±3.73	7.00	13.88	0.02	1.36	1.36
Min 6	8.33±3.73	7.00	15.00	0.02	1.36	1.35
Min 7	8.50±3.87	7.00	16.81	0.01	1.57	2.27
Min 8	8.58±4.10	7.00	20.70	<0.01	1.73	3.01
Min 9	8.83±4.55	7.00	20.70	<0.01	1.69	2.45
Min 10	8.83±4.55	7.00	20.70	<0.01	1.69	2.45
Min 11	8.83±4.55	7.00	22.54	<0.01	1.69	2.45
Min 12	9.00±4.75	7.00	23.54	<0.01	1.78	3.03
Min 13	9.42±5.05	7.50	23.54	<0.01	1.65	1.84
Min 14	9.42±5.05	7.50	25.54	<0.01	1.65	1.84
Min 15	9.42±5.05	7.50	25.54	<0.01	1.65	1.84
LF TENS						
Min 1	9.42±4.32	8.50	18.63	0.01	1.89	4.51
Min 2	9.58±4.38	8.50	19.17	0.02	1.69	3.66
Min 3	10.08±4.96	9.00	24.63	<0.01	2.21	5.97
Min 4	10.50±5.32	9.00	28.27	<0.01	2.07	4.99
Min 5	10.67±5.52	9.00	30.42	<0.01	2.20	5.65
Min 6	10.75±5.48	9.00	30.02	<0.01	2.20	5.71
Min 7	10.83±5.73	9.00	32.88	<0.01	2.30	6.17
Min 8	10.83±5.73	9.00	32.88	<0.01	2.30	6.17
Min 9	10.92±5.70	9.00	32.45	<0.01	2.30	6.24
Min 10	11.08±5.88	9.00	34.63	<0.01	2.46	6.93
Min 11	11.50±6.22	9.00	38.63	<0.01	2.29	6.11
Min 12	11.50±6.22	9.00	38.63	<0.01	2.29	6.11
Min 13	11.75±6.66	9.00	44.39	<0.01	2.51	7.12
Min 14	11.75±6.66	9.00	44.39	<0.01	2.51	7.12
Min 15	11.75±6.66	9.00	44.39	<0.01	2.51	7.12

Table 6m : Raw data for current intensity during pain induction in experiment 6

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Sub 7	Sub 8	Sub 9	Sub 10	Sub 11	Sub 12
HF (100Hz) TENS												
Min 1	24	8	8	11	10	7	8	6	6	18	7	8
Min 2	24	8	8	12	10	8	8	6	8	18	6	8
Min 3	27	9	8	12	10	9	9	6	8	18	6	9
Min 4	28	9	8	12	9	10	9	6	8	18	6	9
Min 5	29	9	8	12	9	11	9	6	8	17	6	9
Min 6	29	10	8	12	9	5	10	6	8	17	6	9
Min 7	29	10	9	12	9	8	10	6	8	17	5	9
Min 8	30	11	9	12	9	9	10	6	8	17	5	9
Min 9	30	11	9	12	9	9	11	6	8	17	5	9
Min 10	30	11	9	12	9	9	12	6	9	17	6	9
Min 11	30	11	9	12	9	9	12	6	9	18	6	9
Min 12	31	11	9	12	9	10	13	6	9	18	6	9
Min 13	31	11	9	12	9	9	13	6	9	18	7	9
Min 14	32	12	9	12	9	9	14	6	9	20	7	9
Min 15	32	12	9	12	9	9	14	6	9	20	7	9
LF (5Hz) TENS												
Min 1	32	7	10	16	14	12	9	7	9	14	14	9
Min 2	32	7	10	16	14	11	9	7	9	14	15	9
Min 3	32	8	10	16	14	13	9	7	9	14	15	9
Min 4	33	8	11	16	14	13	9	7	9	14	15	9
Min 5	33	8	11	16	14	14	9	7	9	14	15	9
Min 6	33	8	11	16	14	14	9	7	11	14	15	9
Min 7	36	8	11	16	15	14	9	7	13	15	14	9
Min 8	36	10	11	16	15	14	9	7	14	15	14	9
Min 9	37	10	12	16	15	14	10	7	14	16	14	9
Min 10	38	10	12	16	15	14	10	7	14	16	14	9
Min 11	41	10	11	16	15	15	11	7	14	18	14	9
Min 12	51	10	11	16	15	15	11	7	14	18	14	9
Min 13	56	10	11	16	15	15	11	7	16	18	14	9
Min 14	57	11	11	16	15	15	11	7	16	19	14	9
Min 15	60	11	11	16	15	15	11	7	16	19	14	9

Table 6n : Summary of current intensity during pain induction descriptive statistics in experiment 6

	Mean±S.D.	Median	Variance	Shapiro-Wilk (p)	Skewness	Kurtosis
HF TENS						
Min 1	10.08±5.45	8.00	29.72	<0.01	1.99	3.50
Min 2	10.33±5.38	8.00	28.97	<0.01	1.94	3.33
Min 3	10.92±5.96	9.00	35.54	<0.01	2.16	4.80
Min 4	11.00±6.21	9.00	38.54	<0.01	2.24	5.24
Min 5	11.08±6.36	9.00	40.45	<0.01	2.38	6.16
Min 6	10.75±6.57	9.00	43.11	<0.01	2.26	5.69
Min 7	11.00±6.42	9.00	41.27	<0.01	2.31	5.99
Min 8	11.25±6.63	9.00	44.02	<0.01	2.35	6.31
Min 9	11.33±6.62	9.00	43.88	<0.01	2.32	6.21
Min 10	11.58±6.50	9.00	42.26	<0.01	2.37	6.38
Min 11	11.67±6.58	9.00	43.33	<0.01	2.28	5.78
Min 12	11.92±6.82	9.50	46.45	<0.01	2.29	5.95
Min 13	11.92±6.78	9.00	45.90	<0.01	2.36	6.15
Min 14	12.33±7.22	9.00	52.06	<0.01	2.17	5.04
Min 15	12.33±7.22	9.00	52.06	<0.01	2.17	5.04
LF TENS						
Min 1	12.75±6.76	11.00	45.66	<0.01	2.34	6.57
Min 2	12.75±6.80	10.50	46.20	<0.01	2.30	6.32
Min 3	13.00±6.70	11.50	44.91	<0.01	2.30	6.37
Min 4	13.17±6.93	12.00	47.97	<0.01	2.37	6.78
Min 5	13.25±6.93	12.50	48.02	<0.01	2.33	6.60
Min 6	13.42±6.84	13.50	46.81	<0.01	2.35	6.79
Min 7	13.92±7.60	14.00	57.72	<0.01	2.48	7.44
Min 8	14.17±7.47	14.00	55.79	<0.01	2.53	7.70
Min 9	14.50±7.66	14.00	58.63	<0.01	2.58	7.94
Min 10	14.58±7.93	14.00	62.81	<0.01	2.63	8.18
Min 11	15.08±8.76	14.00	76.81	<0.01	2.66	8.20
Min 12	15.92±11.50	14.00	132.26	<0.01	2.99	9.71
Min 13	16.50±12.87	14.50	165.73	<0.01	3.05	10.02
Min 14	16.75±13.12	14.50	172.20	<0.01	3.05	10.00
Min 15	17.00±13.96	14.50	194.91	<0.01	3.10	10.22

Table 6o : Summary of experiment 6 questionnaire responses

	time test lasted (mins)	diff. in int. and unp.	VAS marked approp.?	TENS feel diff. in 2 tests?	one current stronger than another?	words for HF TENS	words for LF TENS	higher intensity selected- HF or LF TENS
sub 1	15	yes	yes	yes	no			HF
sub 2	15	yes	yes	yes	yes	tingling continuous vibrating	pulsed	HF
sub 3	15	yes	yes	yes	yes	buzzing fast soft	beating stabbing pricking	
sub 4	15	yes	yes	yes	yes	fuzzy constant	pulsing throbbing	
sub 5	15	yes	yes	yes	yes	intense	interrupted	HF
sub 6	15	yes	yes	yes	yes	pins and needles	painful	LF
sub 7	15	yes	yes	yes	no			
sub 8	15	yes	yes	yes	no			
sub 9	15	yes	no	no	no			
sub 10	15	yes	yes	yes	no			HF
sub 11	15	yes	yes	yes	no			HF
sub 12	15	yes	yes	yes	no			HF
Total and / or mean	mean = 15	yes = 12	yes = 11 no = 1	yes= 11 no = 1	yes = 5 no = 7			HF = 6 LF = 1

Appendix 7 : Information sheet and consent form for experiments 1-6.

7a : Information sheet for participation in ischaemic pain tourniquet test (Queen Margaret College, Edinburgh).

Title
An investigation of the pain relieving effects of Transcutaneous Electrical Nerve Stimulation (TENS) using the ischaemic pain tourniquet test.

Outline Explanation
You are invited to participate in a study conducted by a postgraduate Chartered Physiotherapist on the analgesic (pain relieving) effects of a therapy called Transcutaneous Electrical Nerve Stimulation (TENS). This study has gained approval from the College's Ethical Committee.

You will be asked to take part in an experimental pain induction procedure which involves a tourniquet cuff (similar to the cuff used in blood pressure measurement) being applied to your non-dominant arm (the arm that you don't usually write with) and inflated to cause a gradual increase in pain intensity. The procedure produces an aching or throbbing in the forearm caused by restricting the amount of blood flowing in the arm. It also produces a numb or "pins and needles" sensation in the arm and hand. These sensations will only persist for the length of time that the cuff is inflated. While the cuff is in place you will be asked to complete a number of hand exercises, and rate your pain at various intervals using validated pain assessment scales. The time that the cuff is inflated will last no longer than 15 minutes on the occasion(s) that you will be tested, however **you may request for the procedure to be stopped at any time**. The pain induction procedure as used here is safe for healthy human volunteers and produces no lasting effect.

There are certain criteria that must be met for inclusion in this study and these are:

- female aged between 18 and 35 years
- student or staff at Queen Margaret College
- no current significant pain / injury in any region of the body
- no recent history (within 6 weeks) of significant pain / injury in any region of the body
- no history of heart problems (e.g. pacemaker)
- no intake of painkillers within the previous 24 hours
- no alcohol consumption within the previous 24 hours

These criteria apply for each time that the test is used. If you are unsure about any condition, illness or current use of medication please ask the investigator before you take part in the test (on each occasion if necessary).

During the pain induction procedure you may be treated with TENS. This is a non-invasive therapy which is in routine clinical use and involves the placement of two electrodes on the affected arm to produce an electrical stimulus. The stimulus may cause you to experience a "buzzing" sensation, with or without associated involuntary muscle contractions. The sensations that you may experience will only last for the length of time that the electrodes are in place and the TENS machine is switched on (i.e. maximum duration of 30 minutes).

The amount of time that you will be asked to donate in order to participate in the study will be approximately 30-40 minutes per testing session. These sessions will take place at approximately the same time of the day (your choice) two days (48 hours) apart.

Note:

(i) You are reminded of your right to withdraw from the study at any time without explanation;

(ii) All data collected will be treated in the strictest confidence. Records stored on computer under the provisions of the Data Protection Act.

Please keep this information sheet and if you should have any queries regarding your participation in the study please do not hesitate to contact either of the following people;

INVESTIGATOR: Kerry Kirk
Room G79
Leith Campus, Q.M.C.
Tel: 0131 317 3663

SUPERVISOR: Denis Martin
Room G87B
Leith Campus, Q.M.C.
Tel: 0131 317 3655

7b : Consent form for participation in ischaemic pain tourniquet test (Queen Margaret College, Edinburgh).

An investigation of the pain relieving effects of Transcutaneous Electrical Nerve Stimulation (TENS) using the ischaemic pain tourniquet test.

I (name) .....
Course (including year) .....

hereby consent to take part in the above investigation, the nature and purpose of which has been explained to me. Any questions I wished to ask have been answered to my satisfaction. I understand that I may withdraw from the investigation at any stage without necessarily giving a reason for doing so.

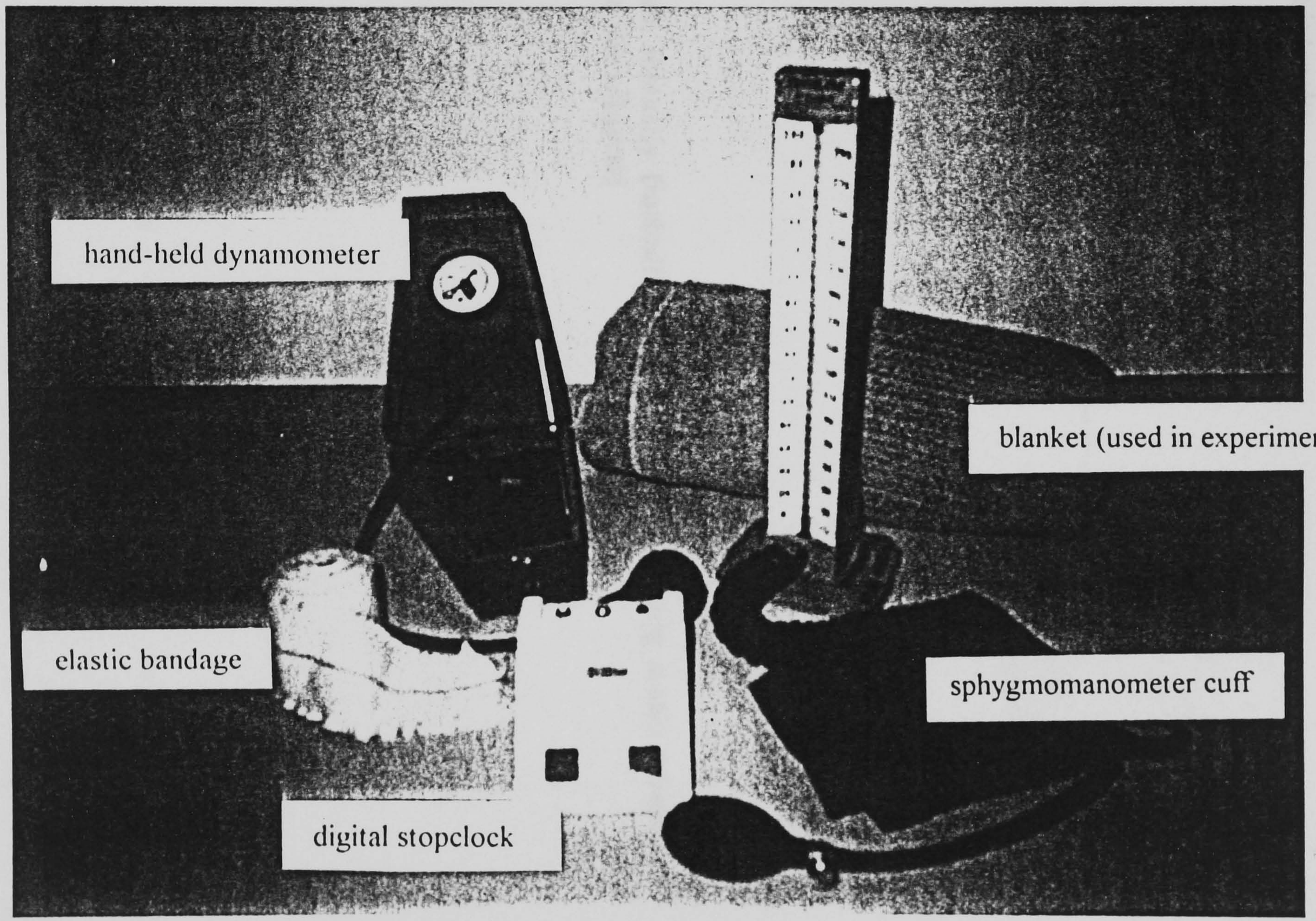
Signed (Volunteer) ..... Date .....
(Investigator) ..... Date .....

If you should have any queries regarding your participation in the study please do not hesitate to contact either of the following people;

INVESTIGATOR: Kerry Kirk
Room G79
Leith Campus, Q.M.C.
Tel: 0131 317 3663

SUPERVISOR: Denis Martin
Room G87B
Leith Campus, Q.M.C.
Tel: 0131 317 3655

Appendix 8 : Photograph of materials and instrumentaion used for pain induction procedure



Appendix 9 : Pain assessment scales for experiment 1.

9a : VAS for pain intensity

PAIN INTENSITY

---

no sensation — the most intense sensation imaginable

9b : VRS for pain intensity (including cross modality matching scores which were not visible to the subjects)

no sensation	0.0
barely perceptible	4.5
very mild	13.6
mild	20.5
moderate	38.2
barely strong	44.8
strong	64.5
intense	72.6
very intense	84.8
extremely intense	95.8
the most intense sensation imaginable	100.0

9c : VAS for pain unpleasantness

PAIN UNPLEASANTNESS

---

not bad at all — the most unpleasant sensation imaginable

9d : VRS for pain unpleasantness (including cross modality matching scores which were not visible to the subjects)

not bad at all	0.0
annoying	18.7
unpleasant	27.6
disagreeable	36.6
slightly distressing	50.2
distressing	62.4
intolerable	73.9
very intolerable	86.5
the most unpleasant sensation imaginable	100.0

Appendix 10 : Pain intensity and pain unpleasantness visual analogue scales for experiments 2-6.

PAIN INTENSITY

no sensation — the most intense sensation imaginable

PAIN UNPLEASANTNESS

not bad at all — the most unpleasant sensation imaginable

Appendix 11 : Ischaemic pain tourniquet test questionnaire for experiment 2.

(1) Did you ask for the cuff to be deflated before 15 minutes of the test had elapsed?
yes / no

(2) If you answered "yes" to question (1), why did you request for the test to stop?
(i) you felt dizzy / light-headed
(ii) you felt sick
(iii) it was too painful to tolerate
(iv) none of the above; please briefly state reason ----------

(3) Did you find it easy to distinguish between pain intensity and pain unpleasantness?
yes / no

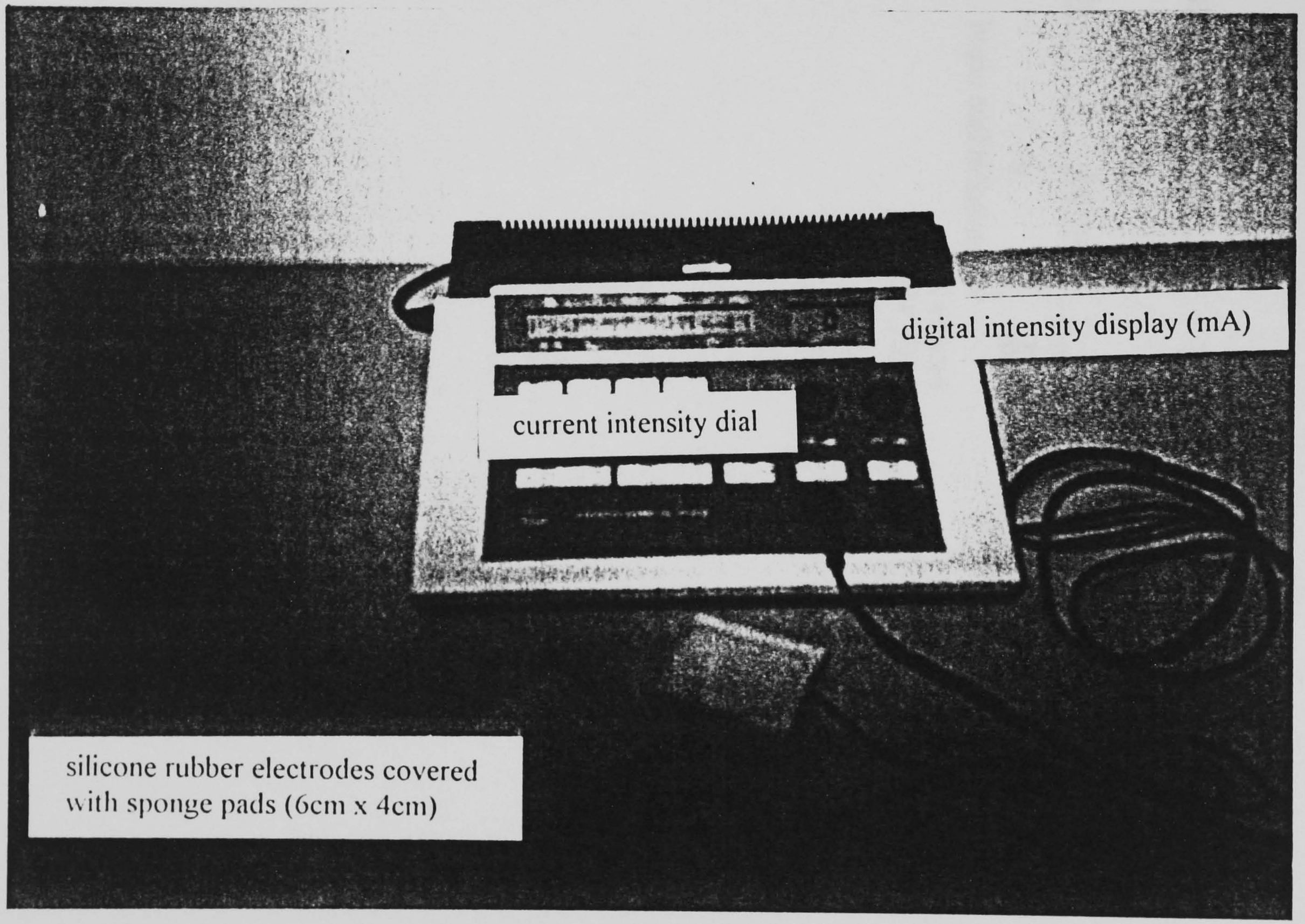
(4) With regards to question (3), do you think you marked the VAS scales appropriately? **yes / no**

(5) Did you notice a difference between the pain produced by the cuff pressure and the pain in the rest of your arm? **yes / no**

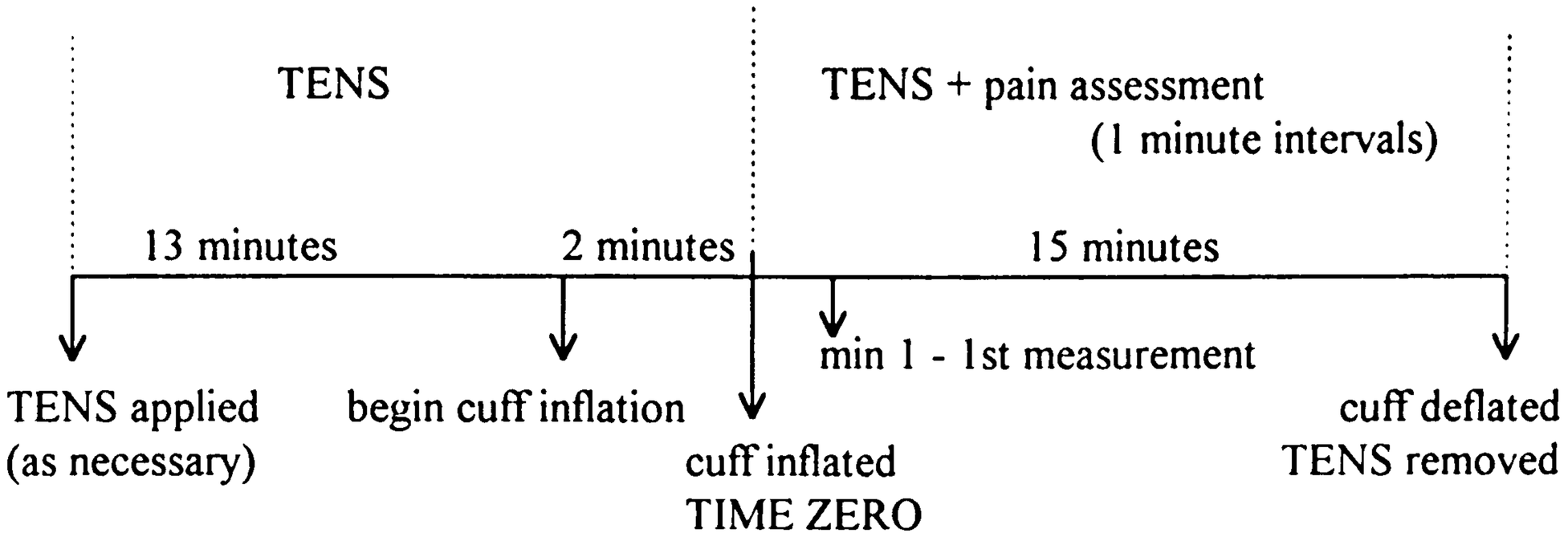
(6) If you answered "yes" to question (5), from where did you find the most pain?
cuff / rest of arm

(7) Any other comments ----------

Appendix 12 : Photograph of TENS machine (Endomed 482, Enraf Nonius Delft) and electrodes



Appendix 13 : Line diagram of experimental procedure in experiments 4 - 6.



Appendix 14 : Ischaemic pain tourniquet test questionnaire for experiment 6.

(1) Did you ask for the cuff to be deflated before 15 minutes of the test had elapsed?

yes / no

(2) If you answered "yes" to question (1), why did you request for the test to stop?

(I) you felt dizzy / light-headed
(ii) you felt sick
(iii) it was too painful to tolerate
(iv) none of the above; please briefly state reason _____

(3) Did you find it easy to distinguish between pain intensity and pain unpleasantness?

yes / no

(4) With regards to question (3), do you think you marked the VAS scales appropriately?

yes / no

(5) Did the sensations from the TENS current feel different in the two tests?

yes / no

(6) If you answered "yes" to question (5), in what way did the TENS current feel different;

(a) Did the TENS current in test I feel stronger than in test 2?

yes / no

(b) Use 3 words to describe the TENS current you received the first time.

_____

(c) Use 3 words to describe the TENS current you received the second time.

_____

(7) Do you think your selection of TENS current intensity differed between the two tests?

yes / no

(8) If you answered "yes" to question (7), during which test do you think you used the higher intensity of TENS current.

1st test / 2nd test

(9) Any other comments _____